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CLASSIFICATION OF WORLD DESERT AREAS

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CLASSIFICATION OF WORLD DESERT AREAS

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FOREWORD

Until recently the challenge of developing a climatic classification oriented toward military requirements has not had much attention. This study strives to overcome that deficiency through development of a pilot system of classification that utilizes the "dry" or "desert" portion of the climatic spectrum as the subject area for analysis.

The approach adopted is unique to the field of climatic classification, standing alone in its dependence on the "rain-day" as the key to delineation. It resolves itself in the form of four classes of aridity, each with six possible subtypes based on thermal characteristics selected for their critical significance to military functions. When applied, the system distinguishes sharply between the given classes of aridity and, in all other respects, appears to satisfy the needs for which it was designed. The method seems to hold promise also for adaptation to the more encompassing problem of classifying world climates. This possibility ensues because the "aridity" formula basic to the study can be modified to permit climatic typing at all levels on the moisture scale. Yet, the problem of classifying world climates according to their most important military characteristics is not an easy one to solve. Many complicating ramifications are associated with the concept, and perhaps a completely satisfying answer may never be found. Whether this line of endeavor is destined to end in success or not, it nonetheless seems clear that the present study contributes substantially toward a solution to the problem and, at the same time, constitutes a valuable addition to the growing store of information being assembled on the interactions between environmental factors and military activities.

The Project Officer for this contract was Mr. Howard L. Ohman; the alternate Project Officer was Dr. William C. Robison. Research was conducted under Project 1T062109A129.

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ABSTRACT

This report identifies and maps limits of arid and semiarid regions of the world through application of aridity criteria quantitatively expressed in terms having military significance. Because the dry world includes a wide range of thermal characteristics, from extremely hot deserts of North Africa to extremely cold semiarid Asia, subdivisions were based on features of monthly temperature.

The worldwide distribution of arid and semiarid conditions is presented on one map. Details of both aridity and thermal classification are shown on eight continental and sub-continental maps for Eurasia, Southwestern Asia, North Africa, South Africa, Australia, South and Central America, Europe, and North America. Aspects of climate and terrain that are of significance to Army operations are described.

CLASSIFICATION OF WORLD DESERT AREAS

I. Introduction

This report identifies and maps limits of arid and semiarid regions of the world through application of aridity criteria expressed in terms having military significance. Subdivisions based on thermal criteria recognize the wide range of temperature influence in the dry world, from the extremely hot deserts of North Africa to extremely cold semiarid Asia.

Selection of classifying criteria, described in the first part of the report, proceeded from review of existing climate classifications and from extensive literature search relating characteristics of dry environments to Army operations.

The worldwide distribution of arid and semiarid conditions, delineated by the criteria established in this research, is presented on one map. This is followed by map depiction and text description of details of both aridity and thermal classification for eight continental and sub-continental segments of the dry world: Eurasia, Southwestern Asia, North Africa, South Africa, Australia, South and Central America, Europe, and North America. Major climatic and pertinent terrain characteristics significant to military operations are presented in the text.

II. Identification of Arid and Semiarid Climates

1. Review of Classification Criteria

The cores of the world's major deserts would be located in approximately the same places regardless of the criteria used to identify desert climate. The same would be true of the world's wettest regions. However, the extent of these areas of climatic homogeneity and the existence of intervening transitions could vary considerably as a function of the identifying criteria. That the criteria used in previously developed classifications of climate apparently failed to provide the specific kind of regional identity applicable to potential Army decisions was implied by the desire for a new effort at identifying and delimiting arid and semiarid climates "in terms having military significance." An initial step toward achieving a military operations oriented climate classification therefore had to be a review of these criteria. Review was expedited by use of three annotated summaries of climatological classification systems [4, 103, 191].

With regard to precipitation, it was confirmed that most of the more than two dozen classification techniques either were aimed primarily at explaining the distribution patterns of natural vegetation or took note of vegetation difference to delineate climatic types. A chapter in the recent volume of the UNESCO Arid Zone Research Series [147], which includes the "more largely applied indices for characterizing the aridity of a region" from 1900 through 1952, lists nineteen different formulas by which precipitation surplus or deficiency could be computed using records of rainfall and temperature of evaporation. The main concern of all of these is essentially the moisture balance in the upper portion of the ground, in the root zone of the cover vegetation. Once a formula considered to approximate the moisture balance was established, discriminating values or durations of this "index of aridity" were often determined by further reference to the distribution of different classes of vegetation.

Precipitation deficiency is an unquestionable characteristic of arid and semiarid climates. Nevertheless the magnitude of deficiency that would affect plant growth might not be the magnitude that could produce direct or indirect effects having military significance. Soil moisture (or lack of it) can be a limiting influence on some aspects of military operations, particularly in relation to trafficability, and may be a function of climatic characteristics that produce other influences. However, the contributing precipitation amount, intensity, and frequency may well be of a different order of magnitude from those critical to vegetation and represented in the existing indexes of aridity. In this respect, none of the many techniques of evaluating climatic homogeneity clearly portrays the world's arid and semiarid regions directly relevant to military operations or to any people who may live permanently or temporarily in these regions. It seemed probable that neither a simple conversion of any already developed aridity index nor even the patterning of a new index on any of the old was likely to produce an "aridity" formula, quantitatively expressed in terms having military significance.

The thermal criteria of existing climate classifications were confirmed by the review as being even less directly applicable to operational questions than the aridity indexes. In several classifications, arid and semiarid types are subdivided only into very gross, pseudo-qualitative thermal sub-types, with precipitation deficit the dominant characteristic, and temperatures considered unimportant. Thus, some classification systems subdivide arid and semiarid zones into tropical, subtropical, and "moderate" or "temperate" thermal regions. (Where cold becomes the dominant characteristic, as in polar thermal regions, lack of precipitation is largely ignored and polar or subpolar climates are rarely classified as arid or semiarid.) The limit of "tropical" is defined in various ways, but the aim generally seems to be to exclude any place having frost or a dormant plant season due to below-freezing temperatures. There is no such natural break between "subtropical" and "moderate" or "temperate" thermal types.

When actual temperatures are used in defining climatic regions, the values selected are usually either indirectly related to vegetation or are completely arbitrary. In Trewartha's modification of Köppen's classification system [142], arid and semiarid regions are subdivided into "hot" or "cold" subregions according to whether "no month" or "at least one month," respectively, has mean monthly temperature below 32°F. Here, as in some other systems, the mean monthly temperature of 32°F seems to represent cessation of plant growth although this physiologic phenomenon is likely with monthly means as much as 10 F° higher than that. Meigs, in his "World Distribution of Arid and Semiarid Homo-climates" [151], expanded on thermal regionalization initiated as early as 1879 but retained arbitrary quantitative criteria:

Hot	Mean temperature of hottest month above 30°C (86°F) or of all months above 20°C (68°F)
Mild	Mean temperature of all months between 10°C (50°F) and 30°C (86°F)
Cool winter	Mean temperature of coldest month between 0°C (32°F) and 10°C (50°F)
Cold winter	Mean temperature of coldest month below 0°C (32°F).

Although the shortcomings of the arithmetic mean as a summarizing parameter for climatic statistics have been pointed out for nearly one hundred years, it has remained the primary and almost only parameter used. On the other hand, most correlations of weather elements, particularly temperature, with distinct facets of military operations, are apt to use instantaneous or synchronous observations. It may be nearly impossible to interpret the significance of climate in relation to human or equipment response, when climate is defined and described only in terms of arithmetic means. In the last two or three decades, an increasing number of analyses of climate have been made using observed frequency of specific weather conditions, but little of this type of analysis has been translated to climate identification and regional delineation.

It was concluded from the review of the major efforts at climate classification that a completely new approach was mandatory. The attempt had to be made to find quantitative expressions of important climatic characteristics impinging on military operations and to produce a classification of arid and semiarid climates based on them.

2. Classification in Terms of Military Significance

A careful survey of pertinent literature was carried out to find as many relationships between climatic factors and military activities as possible which might be used to derive classification criteria. Simultaneously, since the influence of the entire arid and semiarid environments on military operations was to be described, relationships between terrain features and military activities were also sought. The results of the survey were expressed in a summary of relative importance of individual relationships (Table 1) and, for climatic factors, in quantitative summaries such as Figure 1.

In the preparation of Table 1, the degree of significance of environmental factors on military operations was judged by members of the study team who possessed backgrounds and experience in military science, climatology, geography, hydrology, and meteorology. Those environmental factors considered to exert a pronounced influence on a military activity were assigned a "1" while those considered to exert up to moderate influence were assigned a "2". Absence of a number within the table indicates that there was not considered to be a notable influence.

Broad generalizations can be drawn from Table 1. Many of the them are obvious. The purpose of the study was to focus qualitatively on the military significance of particular environmental factors. Climate is significant in many ways and to many or most aspects of military activities. Temperature was the single most frequent climatic factor, precipitation the second most frequent. Personnel are most affected by heat and humidity. Climatic factors are also particularly significant in relation to storage of supplies and to operations of vehicles and aircraft. Of the Terrain factors, Landscape, characteristics of Relief, Slope, and Surface Materials are most significant overall.

Few objective, quantitative evaluations of the critical stage of most climatic elements with respect to military activities appeared to have been made. Neither the literature nor experts in the field had ready answers to such questions as: "How much rain in what duration of time produces a rainfall surplus? How little rainfall creates a critical deficiency? At what temperature is the weather 'Hot' or 'Extremely Cold'?"

TABLE 3

ENVIRONMENTAL VERSUS MILITARY FACTORS

LEGEND

1 = Environmental factor exerts pronounced influence on military activity

2 = Environmental factor exerts moderate influence on military activity

Blank = Environmental factor exerts no notable influence on military activity

These entries are based on consensus of subjective opinions of a study team.

	Military Operations and Components																																		
		Personnel equipment		Storage of food supplies (Class I)		Medical facilities and supplies				Weapon operation at firing individual or crew served				Munitions: Operations and storage (Class V supplies)					Fuels: Use and storage (Class III supplies)				Vehicle operation				Aircraft: Fixed wing		Aircraft: Rotary		Communication: equipment and use			Construction operations	
	Personnel	(1) Combat support	(2) Non-combat and life support	(1) Preserved: Canned and packaged	(2) Perishable	(1) Permanent structure	(2) Temporary structure	(3) Instruments	(4) Perishable medical supplies	(1) Individual	(2) Mortar	(3) Howitzer and other field guns	(4) Rocket & missiles	(1) Small arms, grenades	(2) Artillery, bomb-	(3) Mines	(4) Incendiaries	(5) Rockets	(1) Aviation gasoline	(2) Motor vehicle gasoline, Diesel	(3) Lubricants	(4) Solids	(1) Wheeled	(2) Tracked	(3) Crossing and fording	(4) Water	(1) Transport	(2) Reconnaissance	(1) Transport	(2) Reconnaissance	(1) Line transmission	(2) Air transmission	(3) Visual transmission	(1) Road building, bridging	(2) Water supply
1.0 CLIMATE																																			
Haze and optical phenomena—shimmer and glare	2									1	1	1	1										1	1	[illegible]	1	1	1	1	1			1		
Fog	1									1	1	1	1										1	1	1	1	1	1	1	1		2	1	2	
Cloud cover—amount and base of lowest ceiling										2	3	2	2										2	2	2	2	1	1	1	1		1	1		
Blowing sand and dust	1	1	3	2	1		1	2	1	1	1	1	1						2	2	2	2	1	1	2	2	1	1	1	1	1	1	1	1	2
Precipitation type, intensity, frequency	1			1	2		1	2	1	1	1	1	1	2	2	2	1	2	2	2	2	2	1	1	2	2	1	1	1	1	2		1	1	2
Moon and star intensity	1									1	1	2	2										1	1	1	1	2	2	1	1			1	2	
Ambient temperature—maximum and range	1	2	1	1	1	2	1	1	1	2	2	2	1	2	2	2	2	1	1	1	1	2	1	1	1	1					2	2		1	1
Humidity—relative and absolute, comfort index	1	2	1	3	1	2	1	1	1					1	2	3	1	1													2	2			
Wind speed direction and turbulent variations	1						1			1	1	1	1		2		2	2					2	2	1	1	1	1	1	1	2	2		1	2
Solar radiation and percentage of sunshine	1	1	1	2	1	2	1		1	2	2	2	2						1	1	1	2	2	2	2	2								2	
Evaporation rate	1		2	1	1				1								2		1	1															
Atmospheric pressure	2																		2	2			2	2			1	1	1	1		2			

TABLE 1 (continued)
ENVIRONMENTAL VERSUS MILITARY FACTORS

LEGEND

1 = Environmental factor exerts <u>pronounced</u> influence on military activity

2 = Environmental factor exerts <u>moderate</u> influence on military activity

Blank = Environmental factor exerts no notable influence on military activity

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	Military Operations and Components																																		
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<u>2.0 TERRAIN</u>																																			
<u>2.1 Landforms</u>																																			
Feature orientation						2	2			2	2	2	2										2	2	2		2	2	2	2		2	2	2	2
Elevation	2					2	2	2	2		2	2	2						2	2			2	2	2		1	1	1	1		2	2	2	2
Relief	2					2	2			2													1	1	1		1	1	2	2	1	1	1	1	2
Slope	2					2	2			2	2	2	2										1	1	2		1	1	2	2	1	2	2	1	2
Surface materials	2					2	2				2	2	2										1	1	1	2			2	2				1	1
<u>2.2 Hydrology</u>	2		2	2		1	2			2	2	2											1	1	1	1					2			1	1
<u>2.3 Vegetation</u>																																			
<u>2.3.1 Ground Level Vegetation</u>																																			
Color	2		1																														1		
Perennials, annuals	2														2		2	2					2	2	2								2	2	
Trunk base size	2									2	2	2	2	2	2	2	2	2					1	1	2	2							1	1	
Shallow rooted—deep rooted	2																						1	1	2									1	
Individual plants vs. plant communities	2									2	2	2	2	2	2	2	2	2					2	2	2				2	2	2		1	1	
<u>2.3.2 Overhead Vegetation</u>																																			
Color	2		1			2	2																2	2	2	2		2	2	2			1		
Perennials, annuals	2					2	2								2		2	2					2	2	2			2	2	2			2	2	
Individual plants vs. plant communities	2					2	2							2	2	2	2	2					2	2	2			2	2	2	2		1	1	
<u>3.0 ANIMAL LIFE</u>	1		2	1		2	2		2																		2	2							

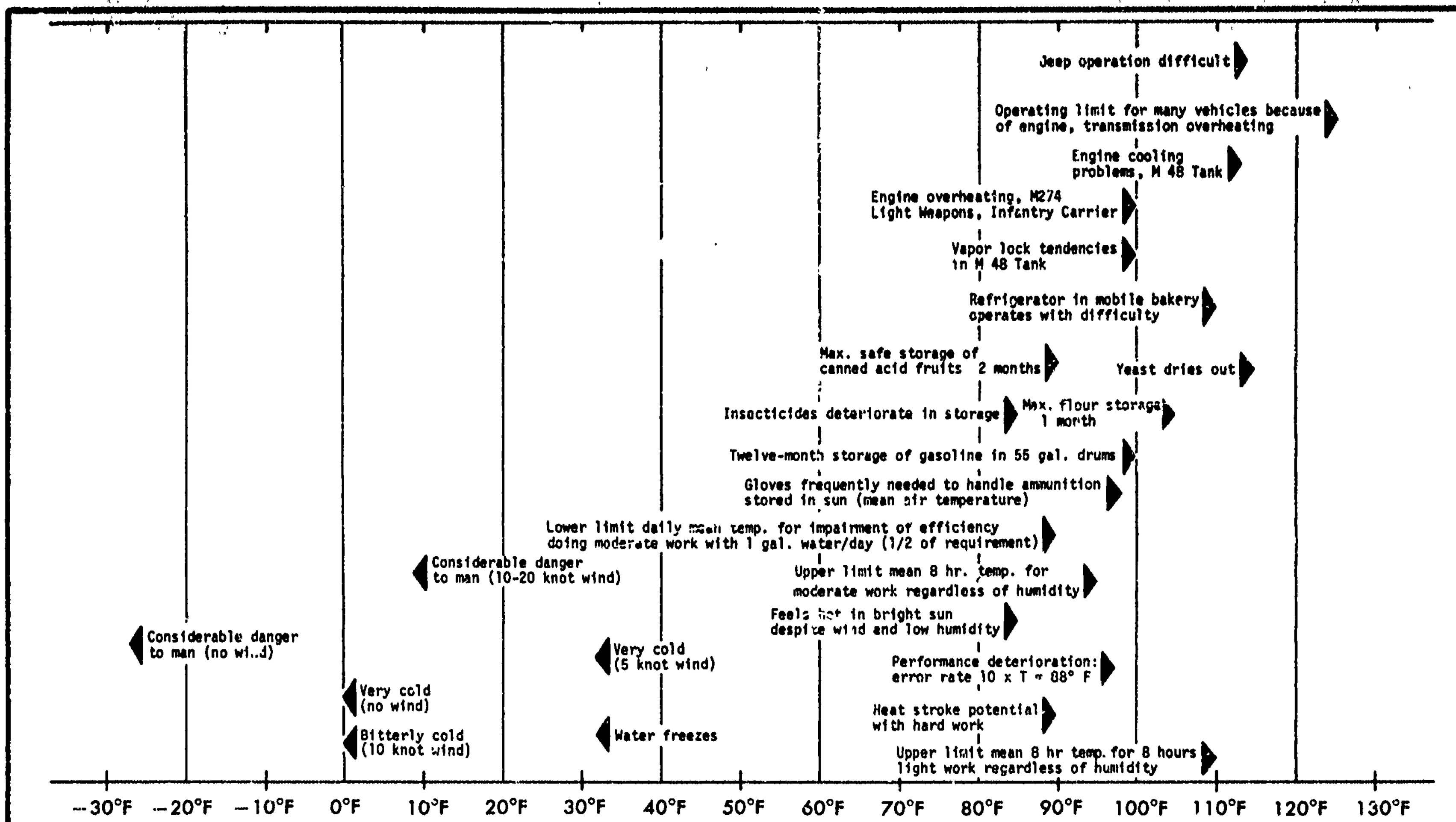

Figure 1. Temperature versus military factors.

Enough quantitative evaluations were found, though, to provide for derivation of workable criteria for the type of climate classification being sought. For precipitation and temperature there were some quantitative answers concerning effects of climate on specific categories of military operations. Regarding precipitation, the critical aspect seemed more to be frequency than amount; for temperature, the critical aspects were whether and how often fairly specific values were exceeded.

a. Index of aridity: number of rainy days

Aridity is more easily delineated by its negative characteristics than by its positive attributes. Not all arid regions of the world have an abundance of sunny or cloudless days nor do they all have low humidity. Not all arid regions have a high evaporation rate. All have a deficiency of rainfall.

Rain generates responses from personnel, supplies, equipment, and their deployment in three somewhat different ways: wetting during its occurrence, change in character of the land surface after it falls, and maintaining a wet environment until it has been removed. "Deficiency of rainfall" within this frame of reference must comprise more than the long-term balance between amount of rain and amount of evaporation. A shower of a few hundreds of an inch of rain can soak clothing, weapons, unprotected stored foods and munitions. Three one-inch rains in a month could leave standing water on the surface of the ground for half of the month while thirty one-tenth-inch rains might produce no standing water at all. Wet clothing might even be comfortable if it dried in a short time, but could be quite harmful if it remained wet for hours. Thus, the important military consideration for precipitation appeared to be the frequency of a quantity sufficient (1) to cause wetting, (2) to accumulate on and in the ground, and (3) to maintain a condition of dampness. Derivation of a militarily significant index of aridity focused first on defining such a "rainy day" and then on evaluating its frequency.

It is likely that the minimum amount of rain within a day that would constitute a "rainy day" for the infantryman is not the same as that which would make a rainy day to the tankman, and so on. For practical purposes, a single threshold value had to be established. It would be a compromise, but closer to the estimate of those who contend with rain directly than to that of those who have at least partial protection. It might also be argued that it makes a difference whether the rain falls in twelve minutes or in twelve hours. However, duration within a day had to be overlooked in this project.

A "rainy day" could be defined as a day on which any rain falls. By this definition, the minimum rainfall on a rainy day would be 0.01 inch or one millimeter, since these are the smallest units in the two most commonly used measuring systems. However, rainfall of these minimum amounts generally does not cause wetting, accumulate, or maintain dampness.

From the viewpoint of rainfall surplus, the maximum free water that can be evaporated within twenty-four hours is approximately 0.5 inch. This represents an average maximum daily rainfall that might be evaporated from impervious surfaces. The actual maximum amount that could be lost by the soil or permeable surfaces is probably nearer 0.3 inch [104].

These minimum and maximum "rainy day" rainfall thresholds placed the definitive value being sought somewhere between 0.01 and 0.30 inch. There were no objective correlations between precipitation rate and personnel well-being, goods deterioration, or equipment efficiency to narrow the focus to a single value. Actually, a single threshold would, of necessity, be an average because response to precipitation rate is itself affected by other environmental elements, especially temperature and type of ground. A threshold of 0.1 inch was finally adopted to define a "rainy day" as a basis for an index of aridity. Rainfall of 0.1 inch or more will cause wetting of absorbent material and standing water on impervious surfaces while 0.01 inch would not. But whereas some value between 0.01 inch and 0.1 inch may well be a wetting threshold, the U.S. Army Corps of Engineers Waterways Experiment Station concluded that a rain storm of less than 0.1 inch does not wet the soil sufficiently to have appreciable effects on trafficability [171]. In addition, it is estimated that throughout the world daily rainfall amount less that 0.1 inch would infrequently leave surplus water after twenty-four hours. Further, in lower latitudes where average rainfall on days when it does rain is 0.6 to 0.8 inch or one and one-half to two times the evaporation, the low threshold of 0.1 inch would, to some extent, compensate for the possibility of surplus water remaining into the second or third day after a rainy day.

The second and equally important phase in the development of the index of aridity in terms of military significance was to establish frequencies of "rainy" days that would distinguish arid and semiarid types of climate. Any month with more than fifteen rainy days can be considered a "wet" month by virtue of simple dichotomy. However, to provide an adjustment for the fact that a "rainy" day can produce anywhere from a few hours to several days of militarily significant effects, the definition of a wet month was selected as a minimum of ten rainy days. This was consistent with data from stations in central Africa within the generally accepted core of tropical rainy climate which show that the six rainiest months have a minimum of ten or eleven rainy days. At the dry extreme are months with no "rainy" days, but, in comparison, a month with nine rainy days is not "dry" merely because it is not wet. Therefore, intermediate or transition categories which might be called "moderately wet" and "moderately dry" were visualized. With this framework, the range of rainy days less than ten per month was divided into three parts: a moderately wet month having seven to nine rainy days, a moderately dry month having four to six rainy days, and a dry month having up to three rainy days.

The year as a whole can be wet, moderately wet, moderately dry, or dry. <u>Semiarid</u> or moderately dry climate was thus defined as having six to nine dry months and the aridity index or formula became "six to nine months having averages of no more than three days per month with 0.1 inch or more precipitation." The aridity index for <u>Arid</u> climates was established as "at least ten months having averages of no more than three days per month with 0.1 inch or more precipitation."

Following the precedent of Meigs [151] and others, it seemed useful to recognize the rather large proportion of the arid climates where rainfall is almost non-existent. The criterion established for <u>Extremely Arid</u> was "at least ten months having averages of no more than one day per month with 0.1 inch or more precipitation." Much of the <u>Extremely Arid</u> climate actually has six months or more with averages of no rainy days—quite a few weather stations in North Africa and Southwest Asia have twelve months with averages of zero days when

precipitation is 0.1 inch or more. The rare rainfalls occur less frequently than one day every two years in any given month.

There are two, quite different, annual regimes included within the semiarid climates: (1) a distinctly dry or arid period, lasting six to nine months, and a rather wet period of three to six months' duration, and (2) ten to twelve months dry and moderately dry, and no more than two months moderately wet or wet. Places with the second regime do not quite meet the criteria established for Semiarid climate, although they often have fewer total rainy days per year than places that do meet the criteria. This is particularly true where just one or two months with four rainy days instead of three causes failure to qualify as Semiarid. These places have been assigned to a subdivision of semiarid climates which has been entitled Demiarid. Its criteria are "four or five months having averages of no more than three days per month with 0.1 inch or more precipitation and a total of at least ten months having averages of no more than six days per month with 0.1 inch or more precipitation."

b. Thermal subdivisions

Considerable research concerning the effects of temperature on personnel, supplies, and equipment has been carried out. Threshold temperatures pertaining to a number of different effects were extracted from many sources and displayed in graphical form to aid in objectively characterizing several thermal subdivisions of the arid and semiarid climates (Fig. 1).

When temperature of the air is between 32°F and 90°F, and humidity is not an additional contributing factor, a usual condition in dry climates, there are few or no temperature-induced problems. Temperatures below 32°F create problems associated with freezing, which become more severe and more widespread the farther the temperature falls below the freezing mark. Above 90°F, the principal problem is achieving adequate cooling, which becomes more acute as the temperature gets higher. The range of temperatures that may be encountered is substantially larger below 32°F than above 90°F. Minimum temperatures as low as -60°F have been observed in arid and semiarid Siberia, and 125°F is the highest observed maximum. It might, therefore, be anticipated that cold thermal categories will have a wider range of temperatures than hot thermal categories.

As with precipitation, establishing thermal subdivisions of climate relating to their military significance was approached from the viewpoint of frequency; how often will temperatures be encountered that may create a certain magnitude of problem? The number of thermal subdivisions to be established was patterned mostly on comfort scales, recognizing that the impact of temperature on personnel is probably more varied and more limiting than on supplies and equipment. Three hot subdivisions, based on frequencies of daily maximum temperatures, were designated as Hot, Very Hot, and Extremely Hot; three cold subdivisions, based on frequencies of daily minimum temperatures, were designated as Cold, Very Cold, and Extremely Cold. The intermediate range, encompassing neither hot nor cold temperatures, was designated as Moderate. Quite a sizable portion of the arid and semiarid zones meet criteria of a hot category in the hottest part of the year and a cold category in the coldest part of the year.

In order to assure that the temperatures indicated for each thermal category occur more than irregularly, it was concluded that at least two months must meet the classifying criteria of mean daily maximum and/or minimum temperature within the specified range. However, the months need not be consecutive.

For the hot subdivisions, critical temperatures seemed to concentrate between 95° and 100°F and between 110° and 115°F. Unfortunately, these represented several different thermal measures: some were temperatures observed in conjunction with the beginning of problems to personnel, supplies, or equipment; others were mean temperatures during the period when the problem developed; still others were mean daily temperatures. Description of the three hot subdivisions will serve best to explain the derivation of thresholds, but it should be emphasized that the values were selected primarily for what they imply concerning the distribution of temperatures, and not because they themselves are directly associated with militarily significant situations.

Hot = mean daily maximum temperature 85—94°F. With mean daily maximum temperature at the lower end of this range, a few days may have temperatures reaching 95—100°F, at the upper end of the range such temperatures are expected nearly half the days. Thus, one to fifteen days per hot month will have temperatures at which performance errors reach ten times the rate that is observed with high temperature near 85°F and at which the limit of eight hours of sustained moderate work is attained. As many as ten days per hot month will have temperatures reaching 100° F, at which munitions handling and vehicle performance problems become noticeable. One-half to all of the days in a hot month will feel hot* in bright sunshine regardless of humidity.

Very Hot = mean daily maximum temperature 95—104°F. One-half to most days per hot month will have temperatures in the 95—100°F range, creating performance problems for personnel and equipment. As many as ten days per hot month will have temperatures in the 110—115°F range, within which the upper limit for personnel of eight hours of even light work is reached and equipment operation develops serious problems.

Extremely Hot = mean daily maximum temperature 105°F and higher. Most days per hot month will be above 95°F, suggesting continuous performance problems. As many as one-half or somewhat more of each hot month's days will have temperatures in the operationally critical 110—115°F range. Temperatures on one or more days will approach the 125°F limitation for the design of many types of equipment.

Cold = mean daily minimum temperature 25—44°F. With mean daily minimum temperature at the upper end of this range, a few days may have temperatures of 32°F and a little below; at the lower end of the range, such temperatures are expected two-thirds or more of the nights in each cold month. These are the frequencies with which problems associated with freezing in vehicles, weapons, and supplies and with near-freezing chill in personnel begin to be noticeable. Concerning the latter, a temperature of 32°F with a 5-knot wind marks the upper limit of "very cold" on some personnel comfort charts.

*This comfort term and others used in defining and describing thermal subdivisions are based on numerous thermal stress studies such as [162].

Very Cold = mean daily minimum temperature 0—24°F. Temperatures below the freezing mark are expected from two-thirds to all of the nights in each cold month; they may be expected to remain below freezing for periods lasting as long as more than half of the days in each cold month. A "bitterly cold" level of comfort is possible on as many as half of the nights and on an occasional day during the coldest months. (Days with "considerable danger" to personnel, qualifying for hazardous duty pay,* will occur at least occasionally when wind is 10—20 knots.) As much as two-thirds of the year will have a potential for problems associated with below-freezing temperatures.

Extremely Cold = mean daily minimum temperature below 0°F. Temperatures are likely to remain below freezing for extended periods; frostbite should be a frequent concern and special care of supplies and equipment is mandatory. Two-thirds or more of the year will have problems associated with below-freezing temperatures.

3. Mapping Arid and Semiarid Climates of the World

Appropriate precipitation and temperature data were mapped and analyzed separately and then combined, with minor adjustments that eliminated very small subdivisions, to yield the maps of distribution of arid and semiarid climates around the world. Data processing and analysis were terminated at 55° N latitude on the premise that by this latitude on the two major northern hemisphere land masses, winter cold is a more dominant feature of climate than the small number of "rainy days."

Monthly tabulations of numbers of rainy days (precipitation ≥ 0.1 inch) were found for only a very few stations outside the United States. For most stations, monthly mean precipitation amount and monthly mean temperature were translated into number of rainy days by using an empirically derived graph, described in the Appendix. Data were obtained from six sources, which are listed here as well as in the Bibliography for the convenience of the reader.

Tables of Temperature, Relative Humidity and Precipitation for the World, Parts I—VI, M.O. 617a, Her Majesty's Stationery Office, London, 1960 [4].

World Climatic Data, 2 parts, Department of Geography, Pennsylvania State University. [103].

Climatological Normals (CLINO) for Climate and Climate Ship Stations for the Period 1931—1960. WMO/OMM, No. 117, TP.52, World Meteorological Organization, Geneva, Switzerland, 1962 [191].

World Weather Records, 1941—1950. U.S. Dept. of Commerce, Washington, D. C., 1959 [183].

Weather and Climate of China. U.S. Army, Rpt. No. 890, 1945 [179].

*U.S. Civil Service Commission, Federal Personnel Manual Letter No. 550-31, June 20, 1967, Washington, D. C.

Worldwide Airfield Climatic Data. U.S. Air Force Environmental Technical Applications Center, Vols. I—VII, 1967—1968 [182].

(The Worldwide Airfield Climatic Data tabulations contain monthly frequencies of days with ≥ 0.1 inch precipitation, which were used when they were based on observations records. However, where they were computed, there were enough discrepancies to make the computations suspect, so the monthly precipitation amount and temperatures were used with the empirically derived graph.)

Use of the six sources was in some cases widespread, in others limited, depending on extent of coverage of the source itself and density of coverage within areas for which a given source had data. Listed by regions established for detailed maps and environmental description, use of the sources was:

Region	Source
Eurasia	4, 191 (USSR), 183 (China), 179
Southwest Asia	4, 182
North Africa	4, 103
South Africa	4, 103
Australia	4, 182
South America	4, 103, 182
Europe	4, 191
North America	4 (Canada, Mexico), 103 (Mexico), 182 (Canada)

For the United States, monthly frequencies of rainy days were compiled for First Order Weather Bureau Stations from tables in Summary of Hourly Observations, Climatography of the United States No. 82, U.S. Department of Commerce. To provide denser coverage, normal monthly mean precipitation and temperature for numerous climatological stations from Monthly Normals of Temperature, Precipitation, and Heating Degree Days, Climatography of the United States, No. 81, U.S. Department of Commerce, 1962, were translated to number of rainy days by use of the empirically derived graph.

Counts of numbers of months with zero to three rainy days were plotted on base maps and the identification criteria for Arid, Semiarid, and Extremely Arid were used to draw lines of delineation. In areas where the climate might turn out to be Demiarid, counts of number of months with zero to six rainy days also were plotted and then the delineation drawn.

For stations within the areas mapped as Extremely Arid, Arid, Semiarid and Demiarid, temperature data were tabulated in the appropriate categories according to the monthly mean daily maximum and mean daily minimum temperatures. After plotting these tabulated frequencies, thermal subdivisions were delineated. The British Tables [4] were the only worldwide source that listed the required maximum and minimum temperatures. In the United States, the basic data came from the Local Climatological Data series prepared by the U.S. Department of Commerce for most First Order Weather Bureau Stations.

LEGEND

	Extremely Arid	10 to 12 months with no more than 1 rainy day per month (a rainy day has ≥ 0.1 in. precipitation)
	Arid	10 to 12 months with no more than 3 rainy days per month.
	Semiarid	6 to 9 months with no more than 3 rainy days per month.
	Demiarid	4 to 5 months with no more than 3 rainy days per month and 10 to 12 months with no more than 6 rainy days per month.

Thermal Subdivisions

(these frequently include parts of two or more adjacent aridity regions; identifying symbol applies to entire area delineated by the heavy dashed line).

EH	Extremely Hot	At least 2 months with mean daily maximum temperature 105°F or higher (this implies temperatures exceeding 115°F up to one-half the days and exceeding 95°F on most days).
VH	Very Hot	At least 2 months with mean daily maximum temperature 95—104°F (temperatures exceeding 95°F at least one-half of the days and exceeding 105°F occasionally).
H	Hot	At least 2 months with mean daily maximum temperature 85—94°F (temperatures exceeding 95°F up to one-half the days).
C	Cold	At least 2 months with mean daily minimum temperature 25—44°F (this implies that temperature will drop to and below freezing up to two-thirds of the nights).
VC	Very Cold	At least 2 months with mean daily minimum temperature 0—24°F (temperature dropping below freezing from two-thirds to most of the nights and below zero as many as half of the nights).
EC	Extremely Cold	At least 2 months with mean daily minimum temperature below 0°F (temperature dropping to -25°F or colder from occasionally to more than half of the nights).
H/C		Denotes thermal subdivision which is Hot part of the year and Cold another part. Many combinations of EH, VH and H with C, VC, and EC occur somewhere in the world's arid and semiarid climates.
M	Moderate temperature	At least 10 months neither Hot nor Cold; no more than 1 month with mean daily maximum temperature 85°F or above and/or no more than 1 month with mean daily minimum temperature 44°F or below.

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GLOBAL DISTRIBUTION OF DRY

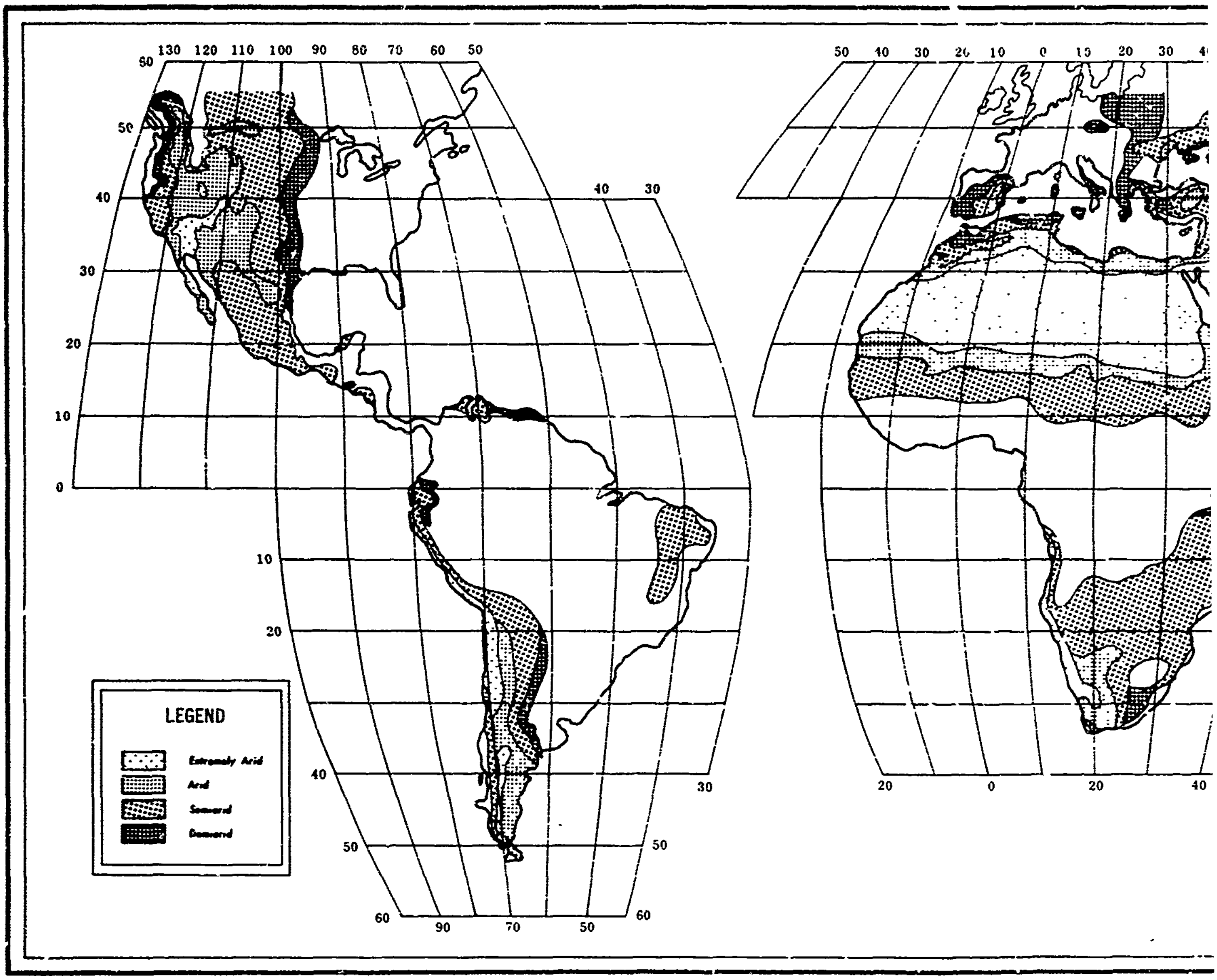
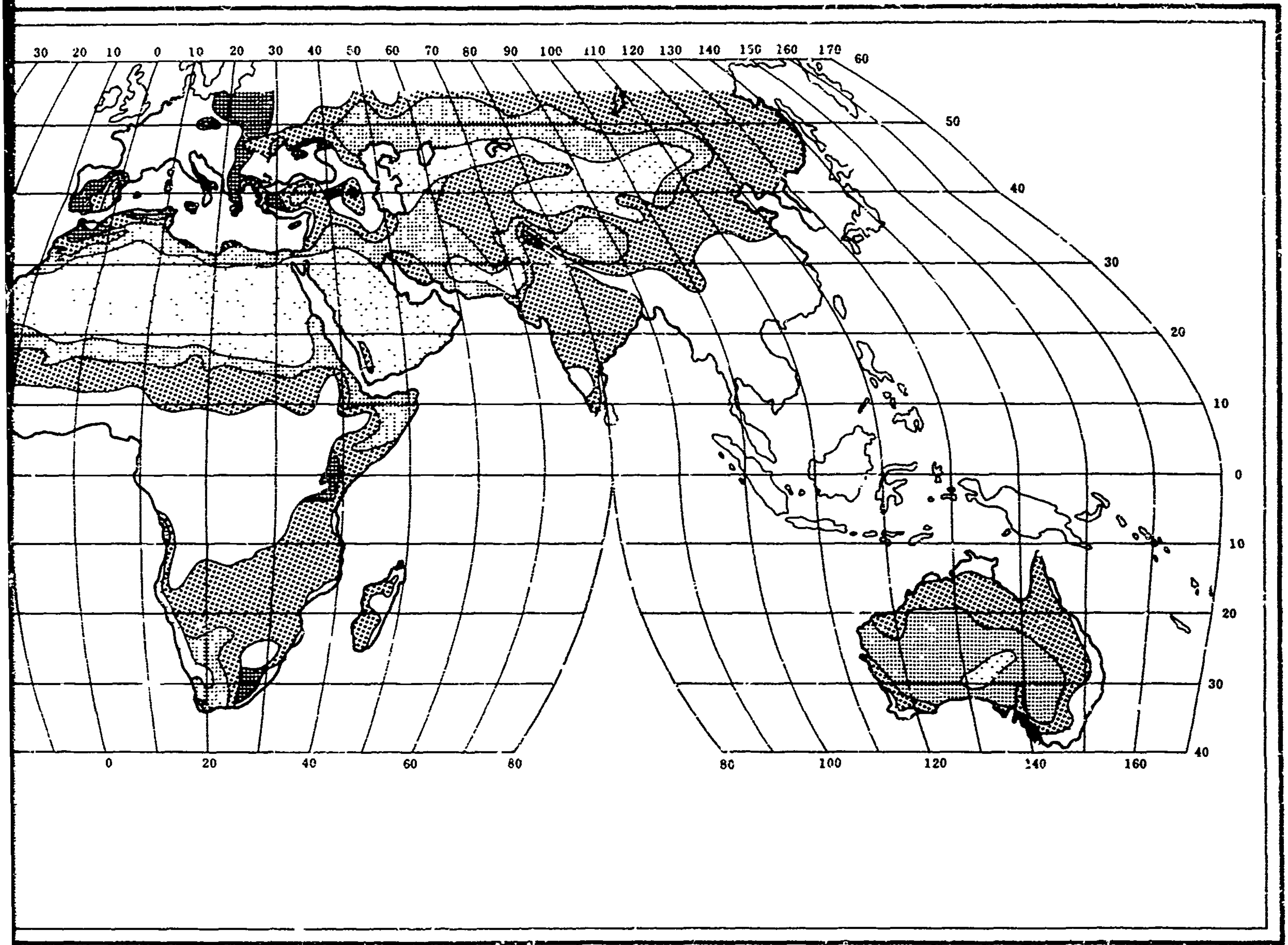


Figure 2

A.

TRIBUTION OF DRY CLIMATIC TYPES



B.

III. Characterization of Arid and Semiarid Environments Having Military Significance

1. Climatic Characteristics

Arid regions contribute more than their share to the list of world extremes of climatic elements (precipitation, temperature, humidity, wind, sunshine, etc.) and the ranges of their spatial and temporal changes. Both the world's highest air temperature and largest diurnal range have been recorded in the dry air of the desert, where vegetation-free ground quickly gives up the sun's heat. The moisture elements, precipitation and humidity, reach their minima not only in the vast continental interiors but also almost to the coasts toward which, rather than from which, the air is usually blown. Right along those coasts persistent cloudiness, though with little rain, may drift a short distance inland from the cool water, but the usual characteristics of arid regions are just the opposite—little cloudiness and much sunshine. Winds themselves are generally not extreme, but when they whip up sand and dust from the barren earth they produce "storms" as potentially harmful as any the atmosphere creates.

Semiarid regions, being transitional, have fewer real extremes, but over the year may be subject to nearly the maxima that both the adjacent arid and wetter climates include.

a. Precipitation

The arid and semiarid climates have a deficiency of rainy days and, at least during the driest part of the year, a deficiency of residual ground moisture. In such climates, rain may become more of a military inconvenience, and possibly even a hazard, than where rainy days are more frequent and rainfall is greater. When it does occur, rain often comes in heavy showers and thundershowers which can produce dangerous flooding, particularly in deep, narrow channels. These are usually dry and are thus attractive for protection from military encounter and, to some extent, from natural elements. Caution is necessary when thunderstorms or heavy showers are thought to be anywhere in the general vicinity because flash flooding does occur at considerable distances from where precipitation falls. Climatological statistics would suggest that flooding is more frequent and perhaps more serious in semiarid regions than in arid regions, particularly at the beginning of the rainy period when water cannot infiltrate the dried out soil as quickly as it would moist ground. Expecially in low latitude semiarid regions, the rainy period is likely to include days on which several inches of rain fall.

Where soils have a high clay content or are salt-encrusted, as on some extensive flats and playa lake depressions, a relatively small amount of rainfall will turn the surface into a slimy plain or saucer on which travel is quite difficult. Where soils are predominantly sand and there is essentially no moisture stored in the upper portion of the ground, small and even moderate rainfall frequently will improve trafficability for at least a short time by firming the sand.

There are three distinctive precipitation regimes within the arid and semiarid portions of the world:

(1) even or random distribution of rainy days throughout the year,

(2) concentration of rainy days in the hotter part of the year,

(3) concentration of rainy days in the colder part of the year.

Each of these is illustrated in a set of climatic graphs (Fig. 3, a—v) for representative stations in the various arid and semiarid types presented according to temperature from Extremely Hot to Extremely Cold. Some generalizations also can be made. In Extremely Arid climates, the few rainy days in the year seem to be randomly distributed as far as any regional regime is concerned. Demiarid climates have relatively even distribution of rainy days through the year. Arid and Semiarid climates usually have a concentration of rainy days in the hotter part of the year on the equatorward side of the aridity core and in the colder part of the year on the poleward side. In the former, rainy days often have very heavy showers and thundershowers; in the latter, rainy days are more likely to be associated with extratropical cyclones, and thus, the rain is not as heavy and is of longer duration.

In higher latitudes and altitudes, where climates are Very Cold and Extremely Cold, "rainy days" may often be snowy days. Using the average conversion of snowfall to rain equivalent, each qualifying day would have at least one inch of snowfall. In some of the world's Arid climates and especially in higher latitude Semiarid and Demiarid climates, snowstorms, drifting snow, and duration of snow on the ground can be real problems.

The wet portion of the year in semiarid climates ranges from just three months with four to six rainy days per month, to six months in which the number of rainy days runs up to twenty or more. Irkutsk in the USSR (Fig. 3-v) and Mapoon in Australia (Fig. 3-j), illustrate the regimes for stations near these extremes.

b. Temperature

Temperature probably has more direct and more widespread impact on the full scale of military activities than any other single climatic element. Its impact is emphasized in arid regions and, to a somewhat lesser extent, in semiarid regions by moisture deficiency. Annual temperature ranges vary from only a few degrees in some coastal arid and semiarid regions (Fig. 3-p, Cape Columbine, Union of South Africa, and Fig. 3-j, Mapoon, Australia) to 70F°or more (Fig. 3-s, Gur'yev, USSR and Fig. 3-u, Semipalatinsk, USSR). Daily ranges also display considerable variation (compare Fig. 3-o, Lima, Peru and Fig. 3-t, Brest, USSR with Fig. 3-d, Fort Flatters, Algeria and Fig. 3-f, Ankazoabo-Sud, Madagascar).

Highlights of the effects of temperature on major categories of military activities on which the notations of significance were based for Table 1 are noted in the following paragraphs. Some have already been discussed in support of the criteria for thermal subdivision of arid and semiarid climates.

(1.) Personnel

Heat and type of work dictate the amount of water needed by personnel in arid and semiarid areas. A man's daily water requirement while doing strenuous work is twenty-five quarts when the temperature is 120°F, ten times his requirement

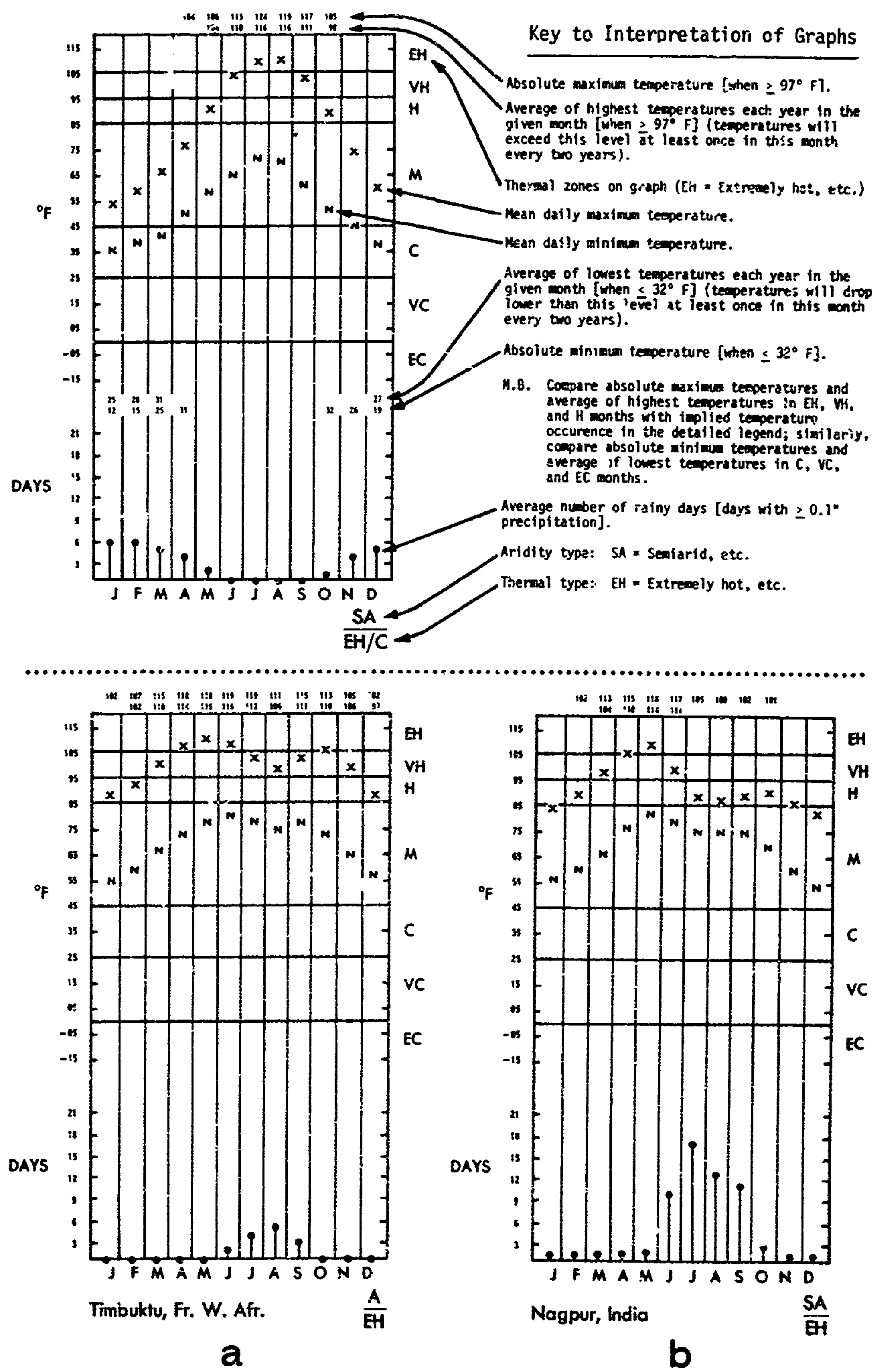


Figure 3. Climographs for selected stations (Showing representative characteristics for various classes of aridity).

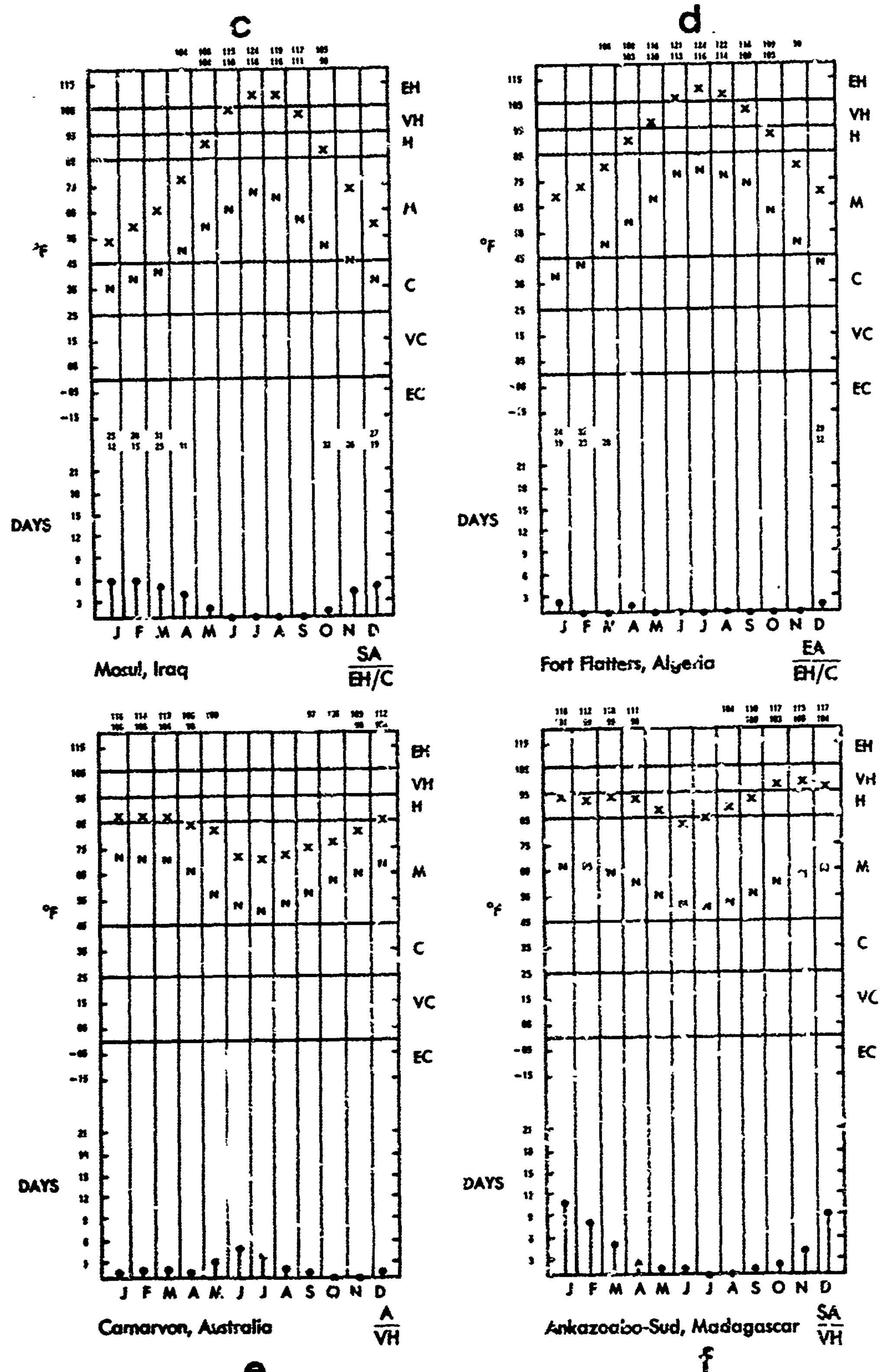
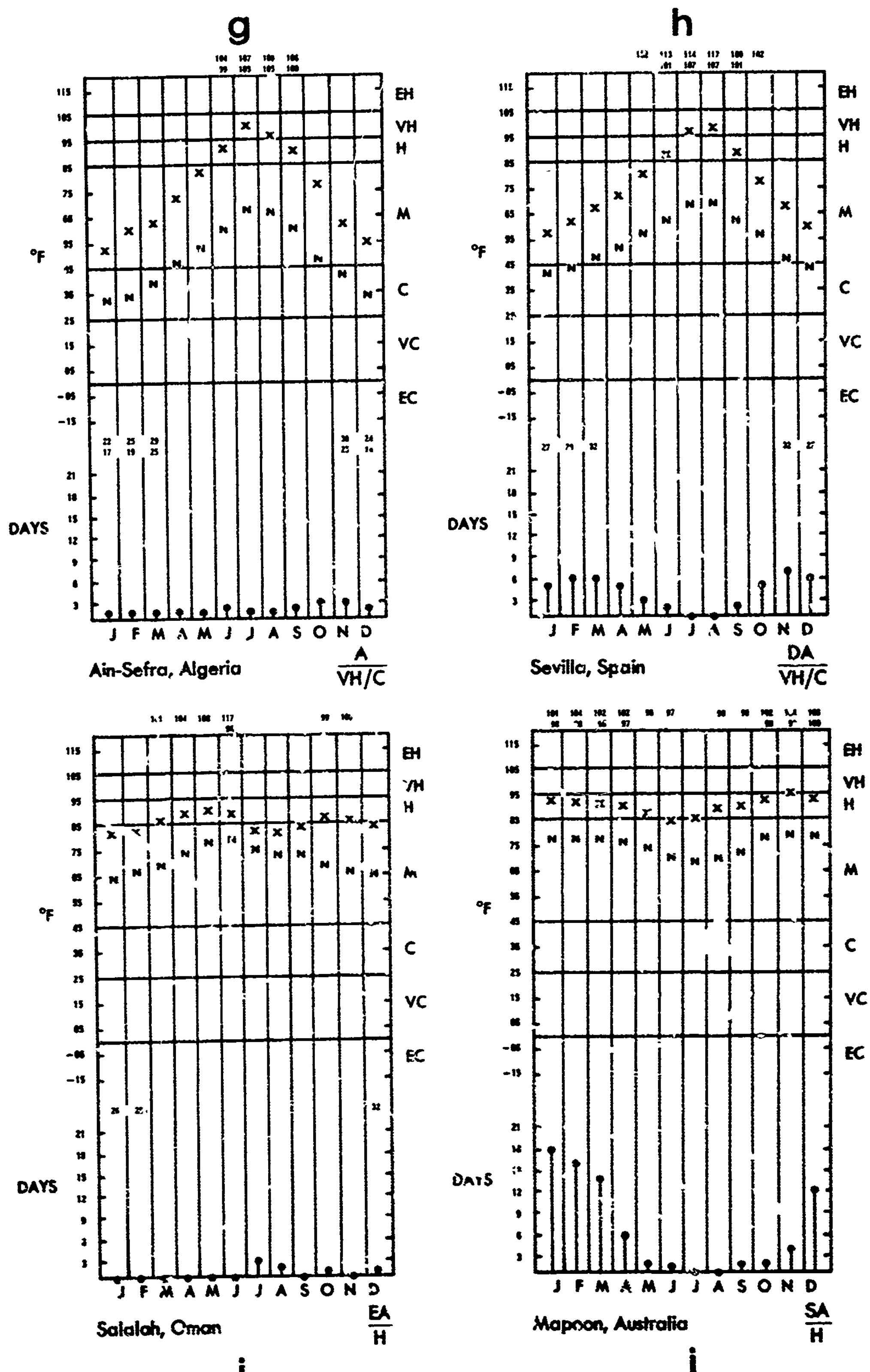


Figure 3(cont.)



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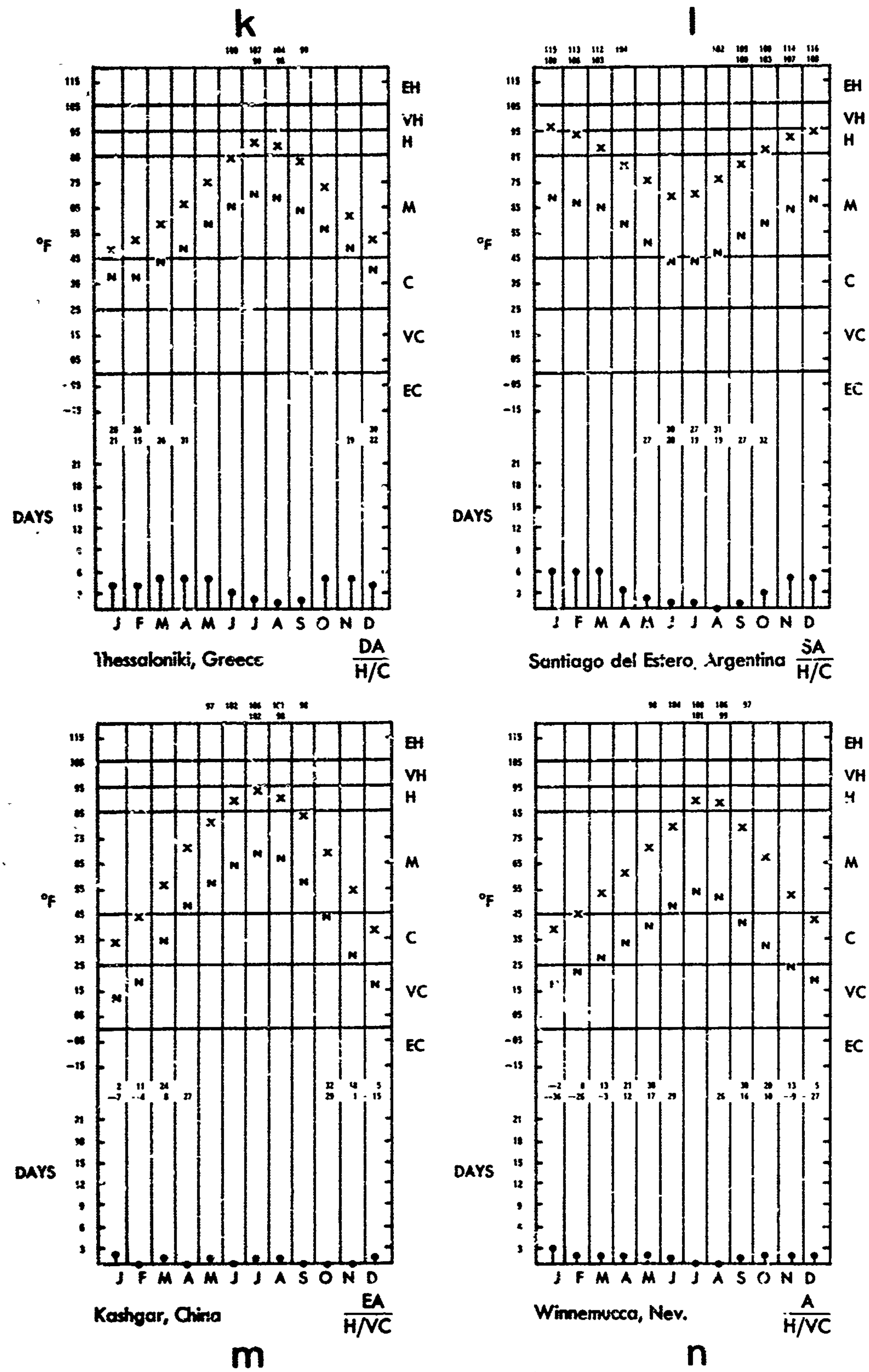

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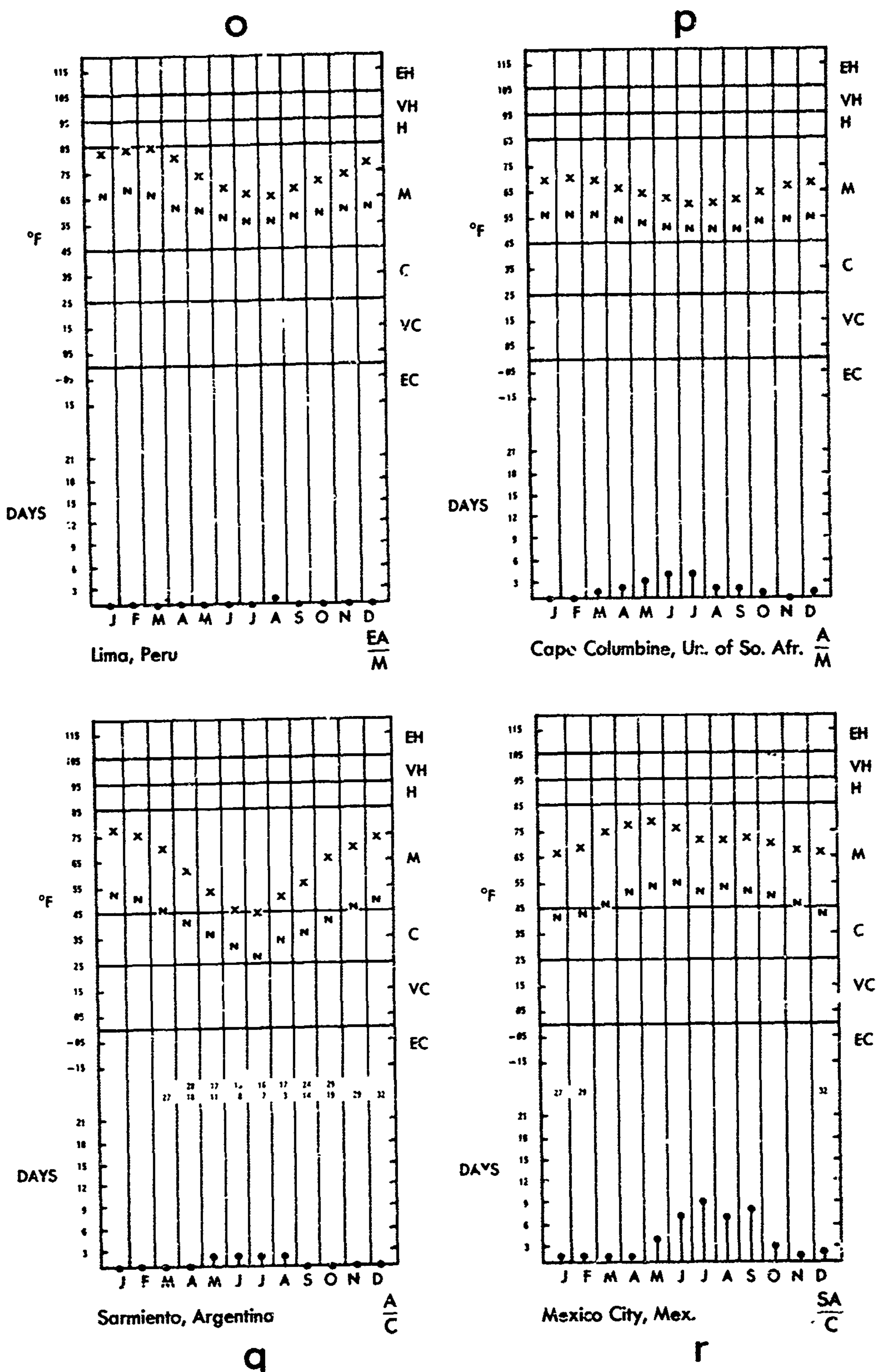

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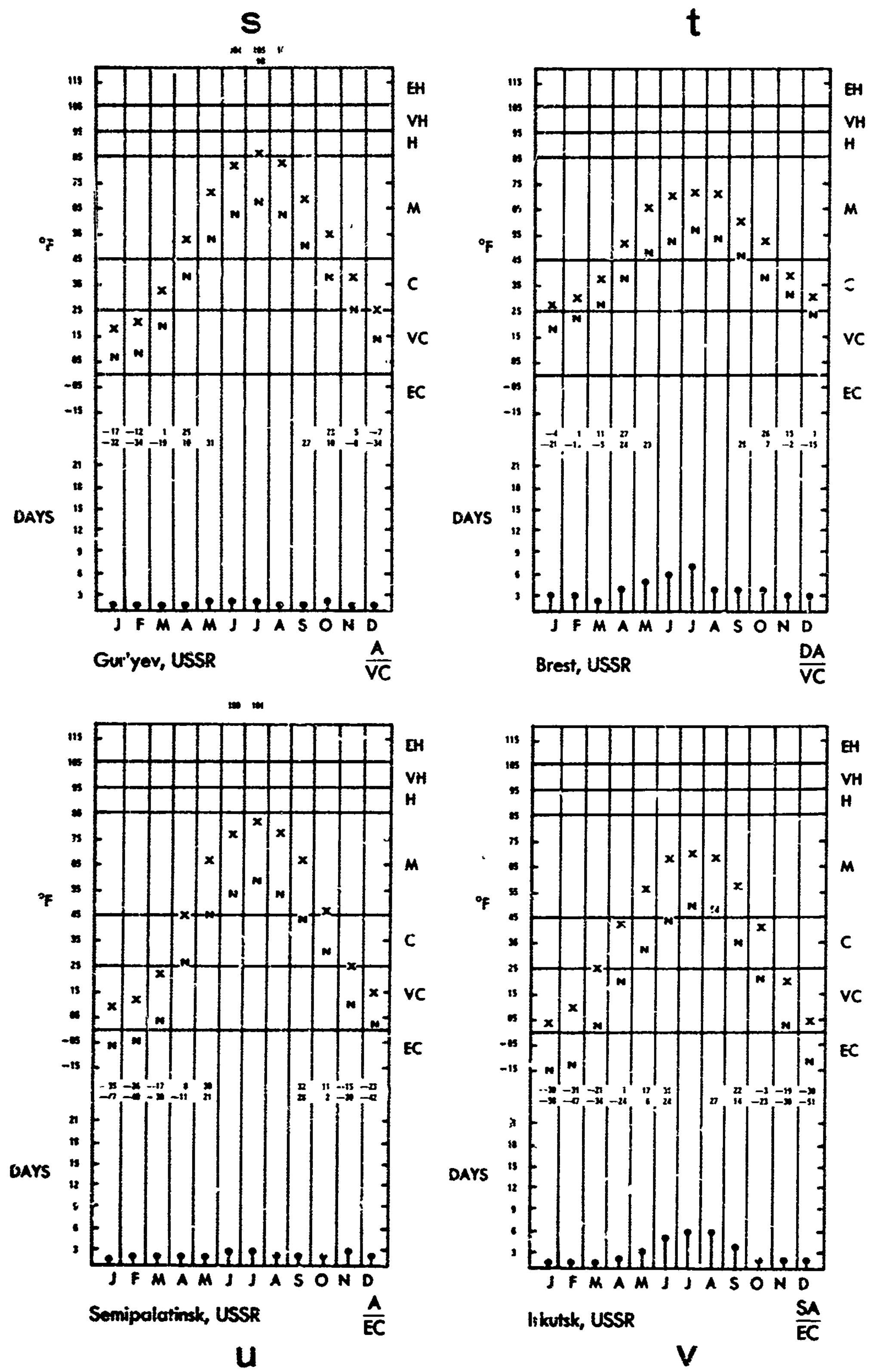

Figure 3(cont.)

when the temperature is 60° F. Operational effectiveness becomes impaired rapidly when water intake is seriously deficient. Survival time for men without water is only two or three days when the mean temperature is above 90°F [162].

Excessive heat alone may cause a reduction in the quality of performance of skilled tasks. While little difference in quality has been noted between work done with temperatures in the 80's from that with temperatures in the 70's, deterioration increases quickly as the temperature climbs from 90° F to over 100°F.

Although heat such as would be common in the Very Hot and Extremely Hot subdivisions greatly increases man's need for water, average food intake has been found to diminish by as much as 10—15%. Perhaps this is related to the finding that slender, acclimatized men with low body fat and brunette skin perform best under hot, arid conditions [135]. The Germans in North Africa during World War II concluded that, after a one to two week period of acclimatization, men operated well in the desert for about a year [141].

Temperature is the important influence of climate on clothing in arid and semiarid regions. Both the extremes of temperature and the daily and monthly ranges must be considered. Impermeable protective suits present problems at high temperatures. Insulated clothing can enable man to endure all but the most extreme low temperatures with relative ease, but heavy gloves make operation of some equipment difficult.

(2.) Storage

A considerable proportion of the world's arid and semiarid area has high temperatures that affect storage of perishable and volatile supplies and/or cold temperatures that affect supplies which can be damaged by freezing. Probably only Moderate and Hot thermal subdivisions are reasonably free of any significant potential storage deterioration due to temperature. Food storage is the most critical, both because the deterioration rate is more sensitive to increasingly high temperatures and because it is less safe to use questionable supplies. Gasoline suffers gum degradation, the rate of which quadruples for each 20 F° rise in temperature.

(3.) Operations

Tests have shown that a number of different types of vehicles develop operating problems when the air temperature rises above 100°F. Some of these problems are mechanical, such as vapor lock, engine overheating, and overheating of transmission oil. Other problems involve personnel discomfort and inefficiency, due to excessive inside temperatures in tanks and truck cabs, where temperatures may run as much as 35—40 F° above outside air temperature.

Low temperatures start to become a problem when freezing occurs, and become critical as temperatures drop to 0°F and below. Freezing of coolant water and any water in the fuel are potential sources of trobule. At lower temperatures, lubricants thicken and available energy in batteries decreases.

The variation of temperature with height over arid and many semiarid surfaces produces a tendency for stable air conditions during the night, an important consideration in employment of chemical agents and a consideration in ballistics. High daytime

temperatures and the consequent decrease of air density are important in ballistics, and may also create a need for longer aircraft runways.

c. Humidity, fog, and clouds

Low daytime relative humidity is a climatic characteristic of much of the world's arid and semiarid area which is both beneficial and detrimental. Throughout a major portion of the Very Hot and Extremely Hot regions, midday relative humidity ranges between 10–25% during the hottest and driest part of the year. Such dryness of the air enables personnel to withstand the heat by increasing evaporative cooling, but it results in dry skin and membranes. Bare metal surfaces rust much more slowly than in more humid climates, but cardboard, leather, and other moisture-containing materials become stiff and brittle.

During the hours just before sunrise, even in the driest areas of the world, relative humidity is frequently in the range from 60–90%. When temperatures during this time are above 75° F, comfort is reduced and it may be unpleasantly oppressive. Close to open water bodies, such as the Red Sea, even the daytime relative humidity remains fairly high and performance of personnel may be seriously impaired.

A few narrow coastal strips with arid and semiarid climate have high to moderately high relative humidity much of the time. There may be persistent fog that has blown in from the open water, and clouds severely limit the amount of sunshine. Both fog and clouds may restrict air operations. There is still little or no rain, but early morning condensation, particularly on metal, is frequent.

The wet part of the year in Semiarid regions and much of the year in Demiarid regions have humidities more like the humid areas of the world than the dry. Comfort and problems of deterioration of materiel are commensurate.

d. Sunshine

A large portion of the world's arid area experiences minimum cloudiness and maximum sunshine. In Extremely Arid and Arid regions, particularly those within 30° Latitude of the equator, sunshine is intense much of the year. The three major problems are severe sunburn, glare (with possible damage to eyes), and optical shimmer. The latter has been found to reduce effective visibility to as little as one-half mile.

Higher latitude Arid regions, and Semiarid and Demiarid regions, may have severe sunshine problems but they are of considerably shorter duration. In the higher latitudes, the sun at its strongest is not as intense. Semiarid and Demiarid regions have more cloudiness to reduce intensity and duration of sunshine, and more vegetation to provide shade.

e. Wind, blowing sand and dust

Wind is another climatic element which has both beneficial and detrimental effects. It increases the cooling rate of the human body by speeding evaporation and is therefore a very important factor in personnel comfort in the hot thermal subdivisions. In cold months, however, wind chill increases discomfort and potential danger of low temperatures.

Most of the arid and semiarid areas of the world have at least occasional "storms" of exceptionally strong and frequently extremely drying winds. The particular characteristics of these winds, such as direction, strength, warning signs, and so on, differ from region to region and are described in detail later in this report.

Perhaps the most hazardous weather condition in the Extremely Arid and Arid regions, where there is little ground cover and where the surface materials are sand or dust, is the sandstorm. Wind-driven sand and dust are very dangerous to breathing, and to eyes and ears; they are serious to both internal and external parts of vehicles, guns, and most equipment; and they contaminate food and other supplies. Blowing sand and dust restrict visibility and thus reduce effectiveness or even make impossible ground and air operations. Sandstorms may last from a few hours to several days; sand, and particularly fine dust, may rise thousands of feet above the ground.

2. Terrain Characteristics

a. Landforms

Effects of the numerous individual characteristics which collectively constitute the configuration and shape of the land surface can be categorized according to slope, relief, surface elevation, and orientation of the major land form elements. Structure of the land contributes to the resultant configuration and shape. It also contributes, proportionately more in arid lands than where there is more complete vegetation cover, to the formation of the predominating surface materials which constitute a fifth category of landform characteristics. Influences of these characteristics of landscape on military operations can be both beneficial and detrimental. Knowledge of them and their effects can enhance the beneficial and minimize the detrimental by assisting in pointing to appropriate strategy. Highlights outlined here may suggest search for more details.

Landscapes in areas with arid climates are notably different from those which develop where there is frequent surface water surplus. Features created by erosional agents are often steeper and seem to be more set on or cut into the overall landscape than to be an integrated part of it. Examples are entrenched streams and dry stream channels (wadis), buttes, and barchans (isolated crescent dunes). In these and in other arid-land features, change of slope can be quite abrupt, a characteristic that might be of more adverse influence on mobility than the slope itself. Further, because of steepness of slopes, relief attains greater importance. Landscape features created by deposition also have a tendency to contrast more with the rest of the terrain than to blend in with it. Outstanding among these are alluvial fans, where mountain streams emerge onto plains, and sand dunes.

The surface of the land in arid areas is also very different from that where water is plentiful. Sparse vegetation, and in wide areas lack of any vegetation, leave the land vulnerable to eroding agents and the surface is often bare rock, stones, or sand, each of which may present special problems to military operations. Wind is an important factor in creating the residual land surface in arid areas, and its action contrasts sharply with that of water. Exposed rock is weathered much more slowly; thus individual elements from small fragments to escarpments and mountain cliffs frequently have more

angular shape. Relatively flat surfaces lose the finer particles and are left with stone- and rock-strewn plains, from gravel and desert pavement to boulder fields. On the other hand, some depositional features provide the smoothest, firmest surface to be found in the deserts: the dry salt flats and playa depressions that collect silts and minerals from evaporating waters of infrequent temporary lakes.

Regions with semiarid climates have landscape types transitional between those associated with aridity and those with more or less permanent wetness, to the extent that climate is related to the development of land forms. A relatively short period with adequate rainfall and continuously above-freezing temperatures can support enough vegetation to reduce drastically the vulnerability of the ground surface to erosion.

The primary influences of landform characteristics on military operations concern mobility. The direct effects of orientation of major landform features and elevation are little different in arid and semiarid regions from those in other parts of the world. Orientation of major landform features is a complex factor because its effects vary not only with each of the other four categories of landform effects but also with important variations in operations. It concerns, basically, accessibility and vulnerability. The world's arid regions consist of about two-thirds barren plains and plateaus and one-third hills and mountains which, in general evaluation, offer poor accessibility and great vulnerability.

The effects of elevation, in any climate, are expressed through atmospheric pressure or oxygen supply and relief of the landscape. It is said that people cannot live comfortably at elevations above 10,000 feet. A surprisingly large portion of the earth's land at that height has arid climate.

The remaining three categories of landform characteristics effects warrant more extensive description and each is the subject of a separate section following.

(1.) Relief

Popular usage gives the term "relief" the connotation of height of hills and mountains on the landscape while more technical usage refers to the depth that valleys are cut into the prevailing upland surface. In either interpretation, large relief is a characteristic of mountains and high plateaus. Rugged mountain terrain, with any climatic conditions, presents numerous operational difficulties resulting especially from limitation of movement to the often narrow, winding, and steep-sided valleys. Arid mountains usually have the added unfavorable condition of lack of protective vegetation. Except where roads have been built, mountain valleys are likely to be impassable for wheeled or tracked vehicles because of the many large rocks that litter the surface.

Large relief in plateaus represents serious obstacles to be bridged. Deep gashes in the otherwise relatively flat surface may be hundreds, even thousands of feet to the bottom. The engineers' skills and available materials may be the most important contribution to success of movement across extensive plateaus in the arid and semiarid regions of the world.

(2.) Slope

The steepness of the land that must be crossed is of considerable importance to both personnel and vehicles. Even on slight gradients movement is slowed and on steeper slopes it can be effectively halted; critical values differ with the type of surface materials. Slopes of 20% can cause traction difficulty on wet soil of high clay content while similar difficulty is not reached on sandy soils until the slope exceeds 30%. Deep, dry sand, however, may create some problem even where there is practically no slope. Sand-dune fields, alluvial fans, washes and wadis, and badlands all have distinctive surface materials and characteristic ranges of slopes. The bare-rock faces of escarpments and mountainsides frequently exceed traversable limits, a characteristic not restricted to arid and semiarid regions.

(3.) Surface materials

The category of arid landscape characteristics which presents the most unique influences on mobility of men and equipment is surface materials. A very small proportion of the world's arid regions is accessible or traversable on modern paved roads and not a great deal more on roads of any type. At the other extreme, a moderate but specifically unknown proportion is impassable because of expanses of deep, loose sand, badlands, large boulders, very heavy gravel, and very deep washes.

The surface material in the Extremely Arid regions is typically bare rock, broken rock, or sand, all of which usually include some hindrance to movement. In addition, all these surfaces become unbearably hot during the commonly cloudless days. Bare rock and boulders cause rapid wear on tires, tracks, and springs. Sharp rocks and stones cause hard wear on tires, tracks and shoes and can cause leg injuries. Rocky surfaces are of particular importance to several military activities: mines are useless but the effectiveness of weapons may be increased by ricocheting fragments of projectiles.

Sand in flat layers and thin sheets is rarely a barrier to travel. Parts of open sand deserts are subject to pockets of fine powdery sand which can mire vehicles. Barchan dunes offer little restriction to movement and provide some beneficial cover and the interdune tracts usually permit sufficient maneuverability. Dune fields, with individual dunes 50 to 300 feet high and little or no space between them can seriously restrict movement. Sand dunes often have a packed crust a few inches thick on the windward slope which may support men and some vehicles; medium and heavy wheeled vehicles will not operate efficiently on dunes. Potentially serious hazards in dune areas are rocks and ledges concealed by sand. Traction is best in sand areas during the early morning when relative humidity is highest and temperature lowest.

Dry salt flats and playa depressions, which commonly have a hard and smooth surface, offer the highest degree of mobility in arid and semiarid regions. The calcium carbonate or calcium sulfate crust may become as thick as six feet and is usually rock-hard. A surface layer of dust sometimes covers the playa depressions and any movement raises clouds of the fine material which reduce visibility, betray movement, and can damage equipment. Unlike the sand surface, salt crust rapidly becomes more difficult to travel when rain wets the surface and makes it slimy and slippery. Heavy rain on salt flats and the brief accumulation of water in the playa lakes turn the hard crust into the consistency of thick porridge.

b. Hydrology

The unique hydrologic features of the world's arid and semiarid regions are functions of the contributing environmental influences not only within the regions themselves but also in adjacent regions. While the combination of low rainfall amount, permeable soil, and sparse vegetation result in limited permanent lakes, streams, and ground water, adequate rainfall and rechargeable aquifers in sometimes quite distant areas may create the exotic streams and underground sources of water that support human occupancy of the dry areas. Surface waters in arid regions and to some extent in semiarid regions frequently have higher suspended particle and mineral counts than those in wetter portions of the world. Underground water, on the other hand, may be cleaner because of extensive mechanical filtering, although its mineral content may also be high.

The few major perennial rivers traversing the extensive desert areas of the world are well known; for example, the Nile and the Tigris-Euphrates. Without exception, these rivers have their sources in regions of abundant precipitation. The lesser and little known intermittent and ephemeral streams may present more problems to military operations, particularly during times of unanticipated flow. Most potentially hazardous are the flash floods in otherwise dry washes, wadis, arroyos, etc.

Standing water in lakes, water holes, and swamps is infrequent in the arid regions but may be common for half of the year or more in semiarid regions. Isolated springs in the deserts may create water holes, usually quite small. Most ponded water that support oases is obtained from wells and aqueducts. The availability of potable water is probably well reflected in the locations and size of permanent or semipermanent settlements.

Hydrologic features are relatively less significant to military mobility in arid and semiarid regions than other features of the environment. In the arid regions, the outstanding problems are the flash flooding and infrequent, shallow but sometimes large playa lakes. Streams and surface water in semiarid regions do not usually produce unexpected problems.

c. Natural vegetation

The color, density, size, and durability of natural vegetation are closely related to the degree of aridity. Vegetation may be completely absent in regions qualifying as Extremely Arid and very sparse in Arid regions. The density and variety increase through the Semiarid and Demiarid climates. However, even nearest the wet climates a closed canopy does not usually exist and, where there are trees, open stands are most common.

Color, in general, tends toward gray and even brown in the arid climates and toward green in the semiarid. Color also reflects the duration of the plant growth cycle. Annuals, sprouting after brief periods of showers or rain and having short lifetimes, are often green and may produce a profusion of brilliantly colored blossoms. These can sharply change the color of the ground surface literally overnight. Perennials, on the other hand, growing where long roots can tap a subsurface water supply, blend more into the overall dull color of the landscape.

Almost nowhere in the world's arid or semiarid regions is the density of natural vegetation such as to cause concern in any aspect of military operations. Probably the nearest it comes to presenting problems is in tangled thickets of low shrubs which have the added detriment to personnel of thick spiny leaves and very sharp, stiff thorns. In semiarid areas, incomplete ground cover of tufted grass may make travel on foot and even by vehicle somewhat difficult but rarely impossible.

Some desert plants store water to the extent that they can serve as life-saving sources under emergency conditions. Few desert plants would provide much nourishment and many contain distasteful and even harmful components. In the Semiarid and Demiarid region, vegetation is of greater abundance and comprises a variety of edible materials.

d. Cultural features

A large proportion of the world's arid area is uninhabited. Permanent transportation routes and communications lines are almost nonexistent. The few that have been established link large areas by a relatively simple system that can be easily disrupted.

The population of arid regions may be classified into two basic types, mobile and sedentary. The proportion of the former has tended to diminish in recent decades. The mobile tribes migrate in constant search of pasture lands for their limited herds. There is little crop agriculture in arid lands, and what has been developed is dependent on underground or distant water supply. "Living off the land" is difficult and precarious.

The limited modern industrial development in arid regions consists mostly of mineral resource processing established by, and in support of, the world's industrial nations. Relatively few of the indigenous peoples are acquainted with today's technology.

Some major cities have grown in arid regions, usually at the fringes and at coastal or navigable river cities. These are not unlike large cities elsewhere in the world.

Semiarid regions are considerably more habitable than arid regions. Particularly outside the tropics they may be quite comfortable places to live and they may support extensive agriculture and industrial development. Where this has taken place, transportation, communication, and the technological advance of the population can match the best attained elsewhere in the world.

3. Animal Life

In Extremely Arid and Arid regions, reptiles, rodents, and arthropods (insects, spiders, and ticks) represent a nuisance and a potential hazard. Each of the world's deserts has its own species, but most have some whose bite or sting can be painful at least and fatal at worst. While some, such as lizards, are active at temperatures up to 100°F, others are likely to be most active at night. Animal life is most abundant near waterholes or other sources of water.

In Semiarid and Demiarid regions animal life is more varied, more abundant, and possibly more useful. In addition to reptiles, rodents, and arthropods, there are mammals, birds, and some fish, as well as domesticated and wild animals, although they may not be of the quality generally accepted by the military.

IV. Characterization of Individual Regions

1. Eurasia

Arid and semiarid climates are continuous from the Atlantic coast of North Africa eastward across Eurasia to the Sea of Japan and the Sea of Okhotsk. Only southeast Asia, Japan, and several smaller areas between the Mediterranean and the Caspian Seas and in European USSR total a large-enough proportion of Eurasia to prevent it from being the world's driest continental unit. Number of rainy days is low enough to classify the USSR as semiarid northward to the Arctic Ocean shore and islands, but in this study it was concluded that north of 55°N the prolonged low temperature is a more decisive influence than lack of rainy (or snowy) days.

For convenience in description, the arid and semiarid climate regions of the USSR and China are covered in this section entitled "Eurasia" while those from the eastern border of the Mediterranean and Red Sea to India are in the next section entitled "Southwestern Asia." With this subdivision, the arid and semiarid climates of Eurasia are all cold, from at least two months with mean daily minimum temperature under 45°F to as many as five months with mean minimum temperature below 0°F.

More than half of dry Eurasia is arid, nearly evenly divided between Arid and Extremely Arid. Oriented west-east across the continent, the arid zone is bordered by Semiarid climate in a horseshoe curve on the north, east and south. From the low plains of the Kirghiz Steppe east of the Caspian Sea, the Arid and Extremely Arid climates extend over progressively higher and more rugged terrain, the elevation of the Tarim Basin and the Gobi averaging nearly 5000 feet above sea level. With limited exceptions, the summer six months in Eurasia (April—September) have more rainy days than the winter six months. This is particularly true in Semiarid climates.

a. Arid environments

(1.) Climate

Precipitation—Extremely Arid regions are less likely than Arid ones to have a pronounced seasonal pattern to rainfall because, by definition ten to twelve months have an average of no days or just one day per month with 0.1 inch or more precipitation. However, in Eurasia periods of two or three consecutive months with no rainy (or snowy) days are more frequent in the west during summer and in the east during winter. This tendency is strong in Arid Eurasia, where the opposite season will often have one or two months with four to six wet days.

The occasional summer days with precipitation usually have showers which very infrequently are moderate to heavy in intensity and rainfall amount. In winter, precipitation is almost exclusively very light snowfall. Seldom is total winter snowfall more than a few inches and the ground is generally bare of snow cover most of the winter.

Temperature—The outstanding temperature characteristics of arid Eurasia are the persistent winter cold and the large annual range. About half of the Arid region and a small eastern portion of the Extremely Arid region have Extremely Cold winters, with two to five months' mean daily minimum temperature below 0°F. In arid parts of Siberia, coldest month minimum daily temperatures may average -20°F.

In the Extremely Arid region adjacent to the eastern shore of the Caspian Sea, winter temperatures are far less severe, classified as just Cold with two or three months when mean daily minimum temperature is at or just under 32°F.

Summers are very warm throughout Arid and Extremely Arid Eurasia, but only in the Extremely Arid Tarim Basin and in a small strip of Arid climate east of the Caspian Sea do two months have mean daily maximum temperatures at or slightly above 85°F, qualifying as Hot.

Humidity, fog, clouds—Early morning relative humidity is commonly between 65—85% throughout the year. At the warmest part of the day, relative humidity varies from 25-40% in summer to 40—60% in winter. Fog is rare, except near the Caspian Sea where it forms occasionally in spring. Cloudiness is more frequent in summer in most of Arid and Extremely Arid Eurasia, corresponding with the period of most rainy days. However, in the Tarim Basin, on the Arid Tibetan Plateau, and in arid regions west of about 70°E, winter stratus may form and persist for several days. The mountain tops surrounding the Tarim Basin are often hidden by clouds.

Wind—Arid and Extremely Arid Eurasia are not notably subject to damaging winds. Strongest winds are observed in winter, an important consideration in view of the incidence of extreme cold.

(2.) Terrain

Landforms—The eastern portion of dry Eurasia, especially the southeast, is one of the most mountainous regions on earth. The Tibetan Plateau, with elevations generally 10,000 to 17,000 feet, is particularly noteworthy. Surrounded by mountain ranges, the Tarim Basin and the Gobi are plateaus at 2000 to 5000 feet above sea level. Hard, claylike soil is thinly strewn with flat gravel and supports sparse vegetation. The Gobi contains a number of small but very desolate deserts.

In the western portion, the land slopes down from the foot of the Tyan Shan to the extensive low plain east of the Caspian Sea.

Hydrology—The three largest inland bodies of water are the Caspian Sea, the shallow, swampy Aral Sea, and Lake Balkhash. None has an outlet, thus all have salt water. Most of the drainage in the western part of Eurasia's arid regions is to one of these three and is intermittent unless fed from high mountain snow. To the east there are few rivers and not many of these survive crossing the deserts.

Natural vegetation—From the Caspian Sea eastward to the plateau-rimming mountains, broadleaf deciduous shrubform trees are scattered over thin grassland. Two strips of deciduous woodland follow the Amu Dar' ja and Syr Dar' ja which flow from the Tyan Shan to the Aral Sea. The eastern half of Eurasia's Extremely Arid and Arid regions have sparse grassland or brushy xerophytes, like sagebrush. Wide expanses of the Takla Makan (Tarim Basin) and Gobi deserts have little or no vegetation.

Cultural features—Population density is generally very low and there are several extensive uninhabited areas. There are widely scattered towns and no cities. There is a limited railway network in the region between the Caspian Sea and the USSR-China border. To the east, surface transportation is primitive by standards of the 1960's.

b. Semiarid environments

(1.) Climate

Precipitation—Most of Semiarid Eurasia, like the arid parts, has dry winters and most of its rainy days are concentrated from May through September. In the three to six wet months in Semiarid regions, though, mean number of rainy days per month increases to maxima between twelve and twenty days. The largest number of wet days per month is observed in the Himalayas at the height of the Indian monsoon. Throughout Semiarid China the wettest month has an average of ten to twelve rainy days per month and across the northern Semiarid strip in the USSR the comparable figure is seven to ten days per month.

Only in a part of the USSR Semiarid climate east of the Caspian Sea is the seasonal pattern different: December through April are the wettest months, maintaining into the interior of Asia the winter cyclonic storm influence that is pronounced in Mediterranean Europe. Frequency of rainy days is only one-third to one-half the maximum in the rest of Semiarid Eurasia, three to seven days per month.

The small Demiarid region along the northeast shore of the Black Sea has three to five rainy days in all months of the year. It gets occasional Mediterranean cyclonic storms in winter and a few showery days per month in summer.

Temperature—As in the arid portion of Eurasia, winter cold is a much more significant influence than summer heat. Only in the Semiarid region east of the Caspian Sea are there at least two months when daily maximum temperatures average 85°F or higher, and are therefore in a Hot subdivision. Even there, winters have low enough daily minima to be classified Cold. The Demiarid and adjacent Semiarid sector near the Black Sea do not have hot summers, and winters qualify as Cold.

The bulk of Semiarid Eurasia is either Very Cold or Extremely Cold in the winter. Eastern USSR is among the coldest portions of the earth, with five or six months when mean daily minima are 0°F or lower. They are often much lower, with stations in Siberia observing mean daily minima of -15°F to -30°F for two or more winter months.

Humidity, fog, clouds—The relative humidity averages quite high during the winter, but at low temperatures the air contains little moisture. Cloudiness is maximum during the winter, with most areas averaging over six-tenths cover. Summer cloudiness is not markedly less than winter, except in the Semiarid region east of the Caspian Sea where average cover may be as little as one-tenth. Fog is common during summer along the coasts bordering the Sea of Okhotsk and the Sea of Japan.

Wind—A few times each winter northeast gales, called "Buran", may blow for several consecutive days. During the summer, winds are light and variable except for brief gusty winds associated with occasional thunderstorms.

(2.) Terrain

Landforms—From the Black Sea eastward to about 85°E, the terrain is relatively flat, both plains and rolling plateau. In eastern China there are some broad plains, but most of Eurasia's Semiarid climate is associated with rugged relief, ranging on up to the Himalayas and other chains surrounding the Tibetan Plateau. There is a moderately large proportion of bare rock surface. Otherwise, soil is thin, frozen

from a few to many months of the year, and may be difficult to travel on in the period of the spring thaw.

Hydrology—Rivers tend to radiate across Eurasia's Semiarid horseshoe, originating near the interior edge of the Semiarid band and flowing toward the Pacific's peripheral Seas or the Arctic Ocean. Many are northward flowing streams, which flood badly at the time of high water and inhibit thaw downstream in the spring. Lake Baikal is the only large inland water body. It freezes solid, with ice as much as nine feet thick, and remains frozen for four months or more.

Natural vegetation—Semiarid climate in Eurasia has not generated a consistent vegetation response. On the plains and plateaus in the northwest and also east of the Caspian Sea, grassland predominates. Elsewhere, forests are more common, but with considerable variation in type of trees and in various proportional mixtures with grassland.

Cultural features—There are two notable features relating to population distribution, with attendant transportation and communication facilities, in the USSR. The Semiarid region east of the Caspian Sea contains a major concentration of population in the eastern USSR. Tashkent, a regional capital, has well over one million inhabitants. Second, there is a narrow strip of moderately dense population extending eastward the whole length of the northern Semiarid perimeter, coinciding with the route of the Trans-Siberian Railway.

In China, well over half of the eastern populated portion of that country is in the region classified as Semiarid climate. There are many large cities, including Mukden, Peking, Tientsin, Tsingtao, and others. Transportation, communications, industry, and commerce may all be measured in the context of this region as a particularly important portion of mainland China.

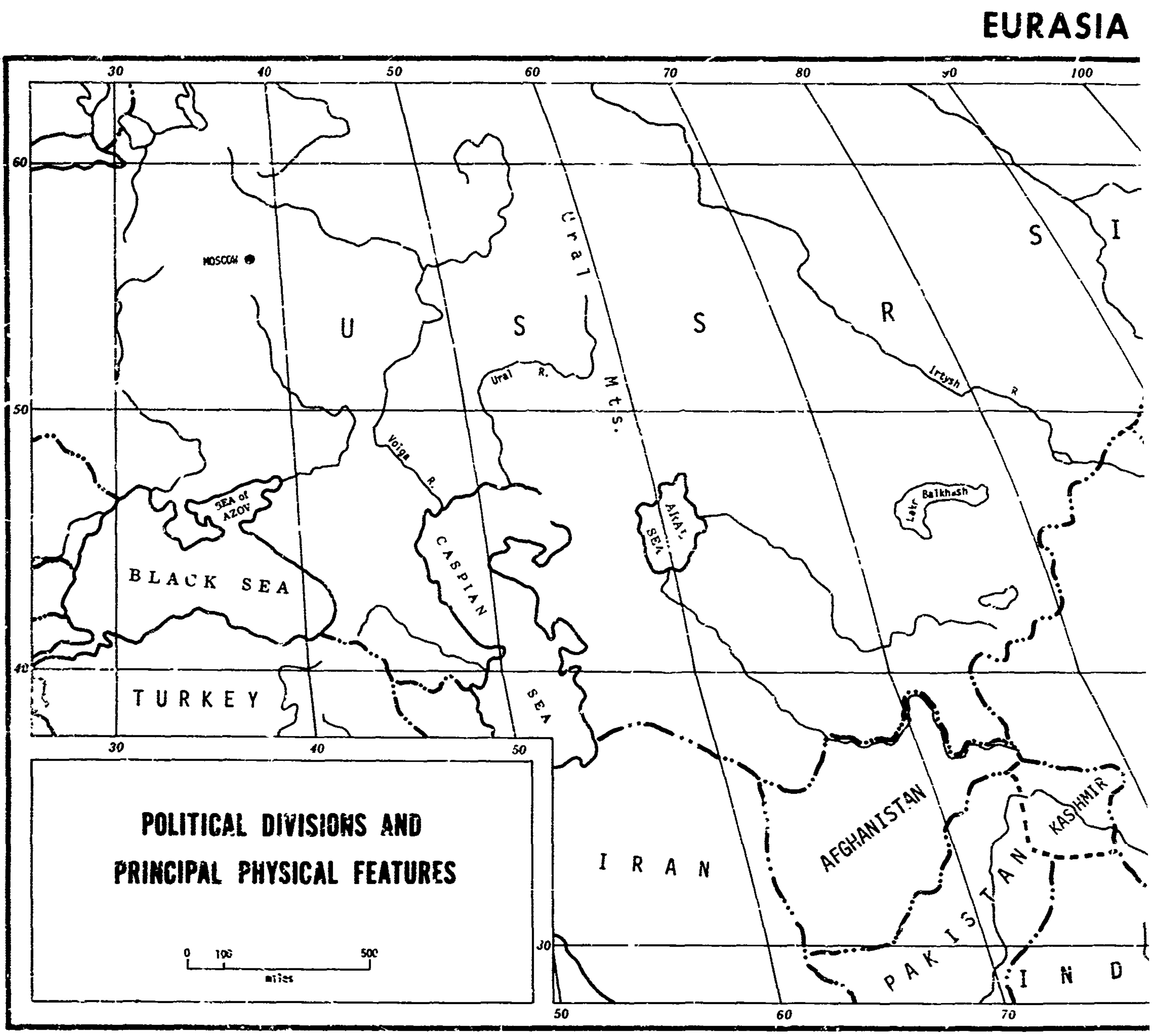
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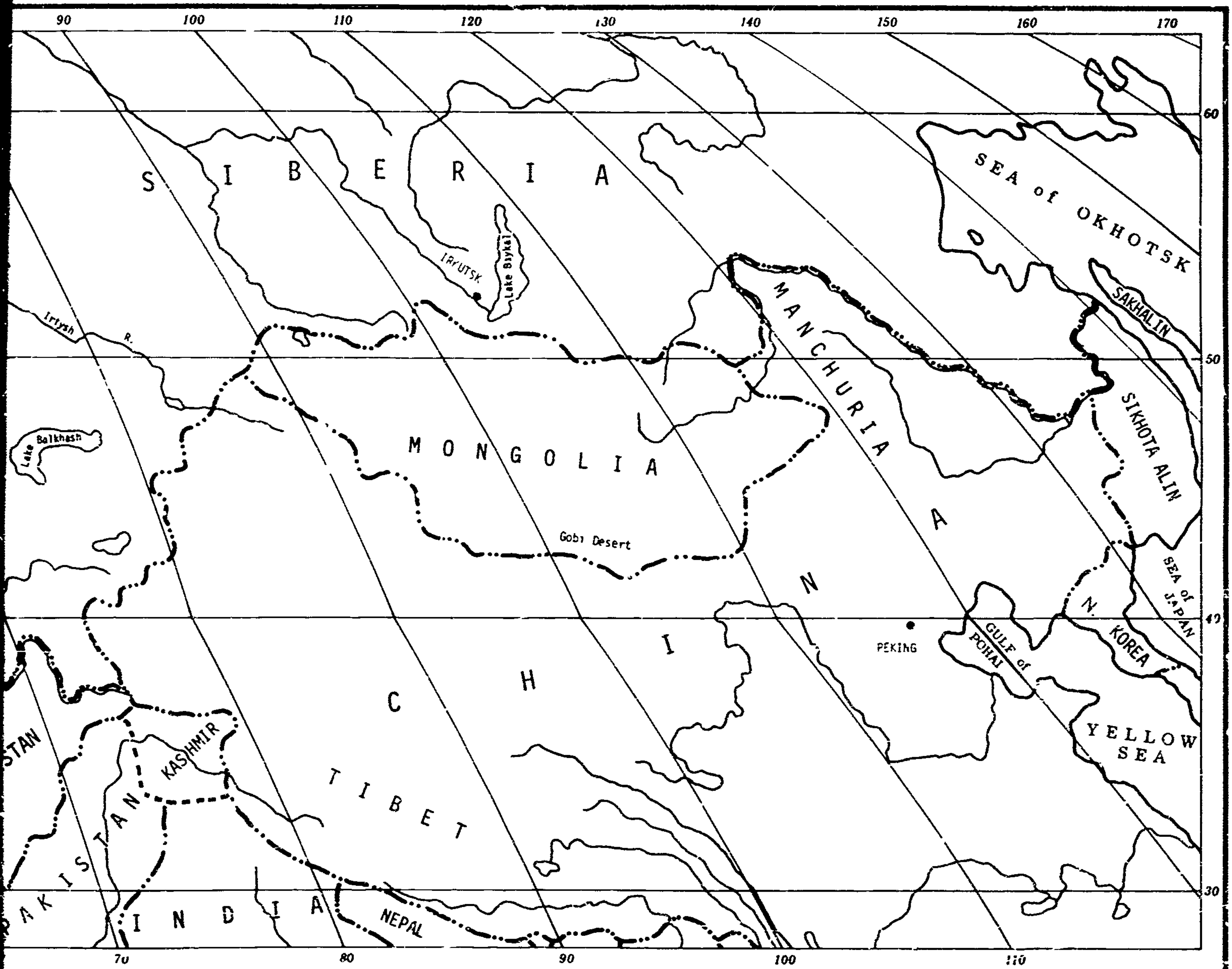
Figure 4

A.

EURASIA



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SAKHALIN
SIKHOTA ALIN
MANCHURIA
Irtysh R.
Lake Balkhash
MONGOLIA
Gobi Desert
CHINA
PEKING
GULF of POHAI
SEA of JAPAN
N. KOREA
YELLOW SEA
TIBET
KASHMIR
PAKISTAN
STAN
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B.

EURASIA
DISTRIBUTION OF DRY (

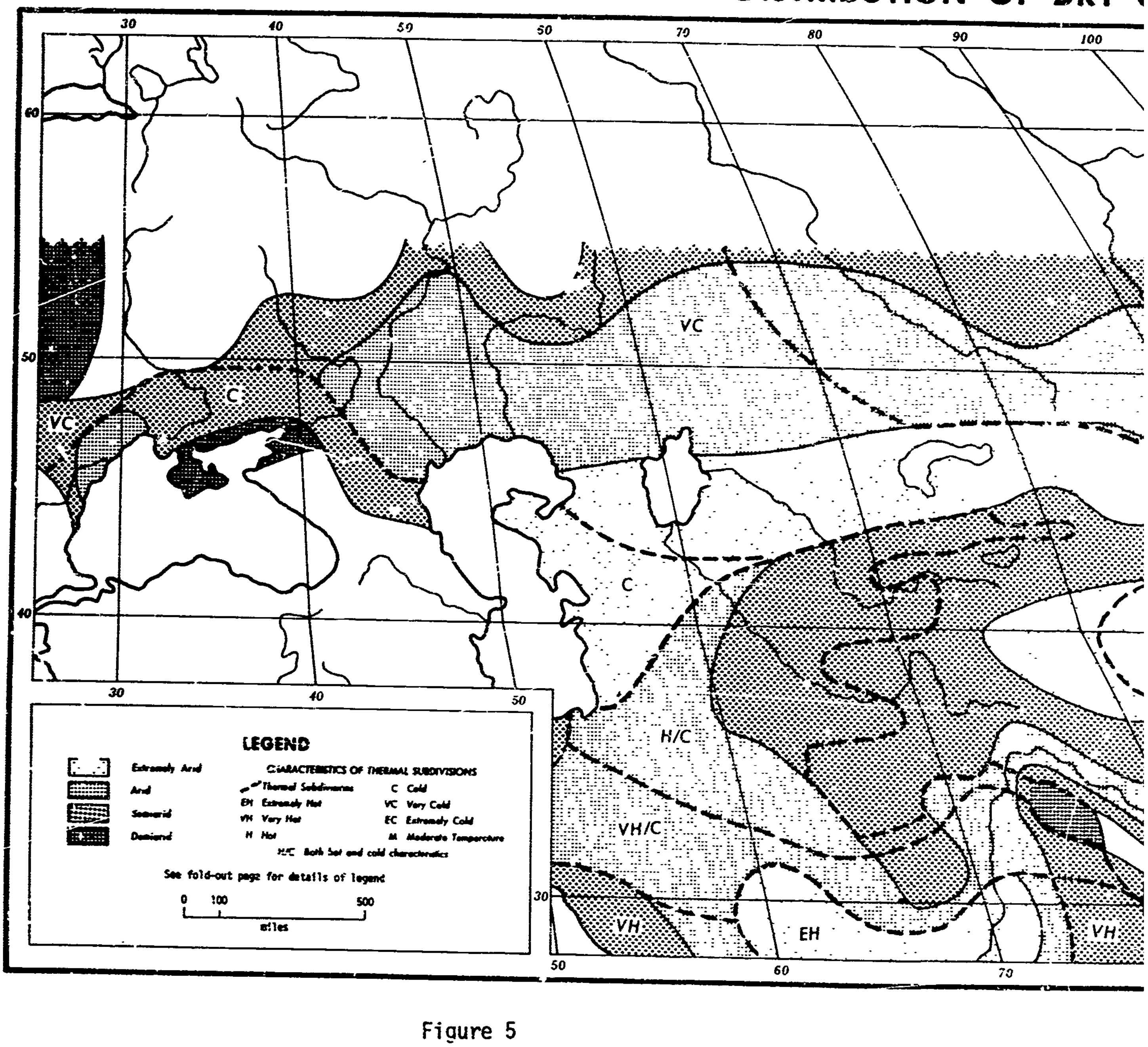
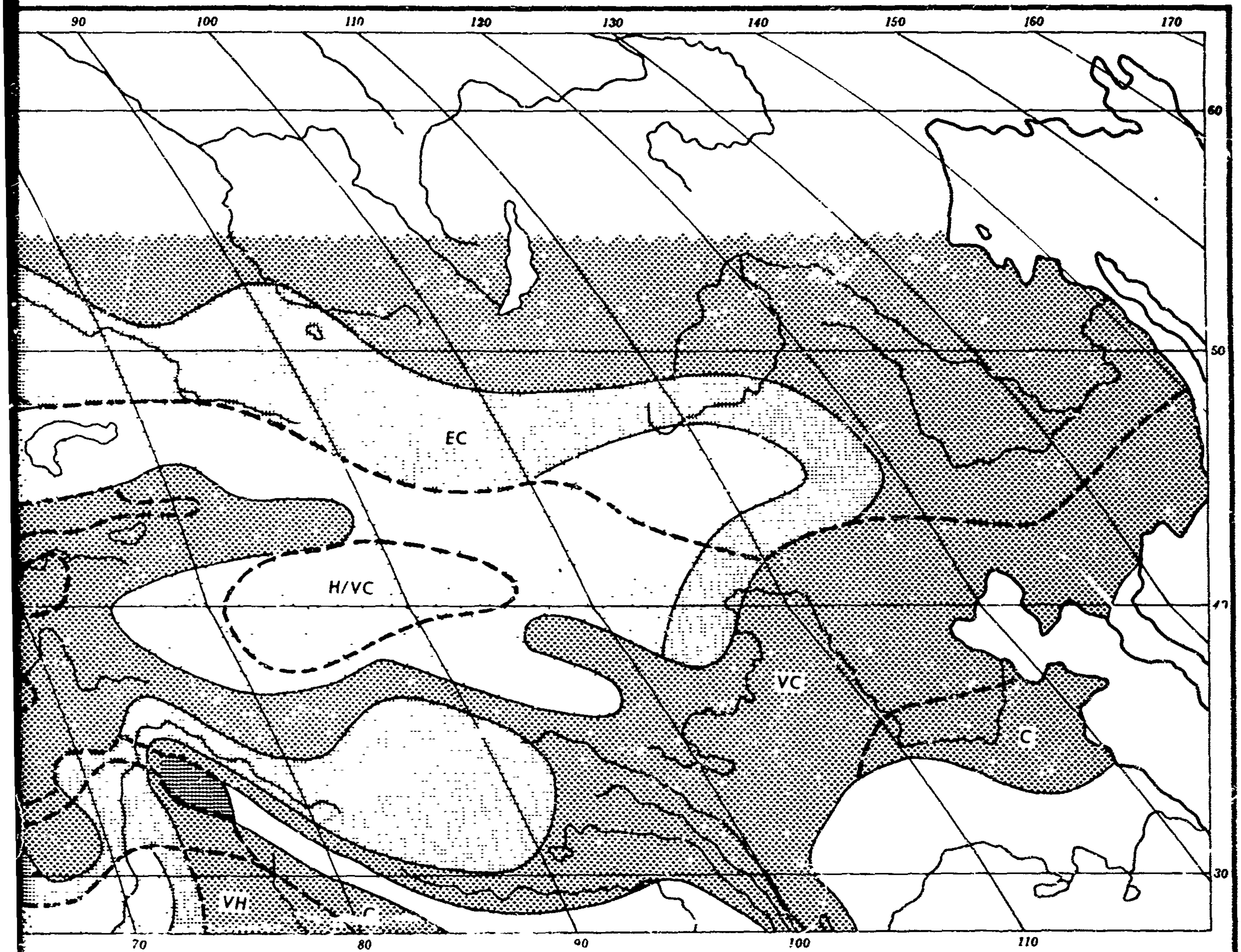


Figure 5

A.

EURASIA
ION OF DRY CLIMATIC TYPES



B.

2. Southwestern Asia

The dry climates of Southwestern Asia have several focii and wide contrasts. The Arabian Peninsula is, climatically, an eastward extension of the North African subtropical desert. India is the definitive example of monsoon semiarid conditions, with widest possible range from winter drought to summer floods. Northwest of India and north of Arabia, aridity prevails but becomes less intense with closer proximity to the Mediterranean, and only West Pakistan and eastern Iran match the dryness of Arabia. Central Turkey, though, despite its peninsular position, is a small island of Arid climate.

Southwestern Asia has additional extremes in its physical environment. The following are found in the Hot to Extremely Hot zones:

(1) World's lowest elevation (Dead Sea, elevation -1297 feet).

(2) World's largest, absolutely vegetationless desert (Great Salt Desert, Iran).

(3) World's largest sand dunes (1000 feet in Rub Al Khali, Saudi Arabia; 700 feet in Lut area of Iran).

(4) World's highest wet bulb temperatures (95°F, Bahrain Island in the Persian Gulf).

Most of the region has summer drought, with winter precipitation produced by cyclonic storms moving through the Eastern Mediterranean area. These weather systems are often accompanied by severe dust storms in the northern portions of Saudi Arabia. In the area bordering the Caspian Sea the precipitation may be snow and it is often accompanied by strong winds and low temperatures. The summers are characteristically cloud free and very hot with excellent visibility. The Red Sea and Persian Gulf add high humidity to the high temperatures of the bordering land to produce an extremely unfavorable climate for human comfort.

a. Arid environments

(1.) Climate

Precipitation—Most of the precipitation is confined to the late winter or early spring. When rains do occur they are commonly heavy showers which can cause local flash flooding. The large Arid zone in Iran almost qualifies for an Extremely Arid classification, with many sections reporting nine months with no more than one rainy day. In Iraq the spring rains combine with the melting snows in the higher elevations of Iran and Turkey to produce widespread floods in the lower reaches of the Tigris and Euphrates.

Temperature—More than 85% of Southwestern Asia's dry climates, all but some coastal sections and more northern areas, are Very Hot to Extremely Hot. The hottest temperatures occur over the deserts of Saudi Arabia and in the interior basins and depressions of Iran and Turkey. In the deep, calm valleys of the south and east portions of Turkey and in eastern Saudi Arabia the air temperature may reach 120°F at least once in each of two or three summer months.

High temperatures are observed for many months throughout this entire region. During four to ten months, mean daily maximum temperatures commonly exceed 85°F. In coastal regions the hottest period is somewhat delayed beyond mid-summer. The Thar Desert area of India is hottest before and after the increase of cloudiness which occurs during the summer monsoon. A temperature of 120°F has been observed in the Thar Desert in May and the average daily maximum temperature in October, over 95°F, is 1—2F° hotter than the two preceding months.

In the northwestern portions of this area (Turkey and northern Iran, Iraq, and Syria), passage of cold fronts bring cold air in the winter. Such cold outbreaks are usually severe in the desert areas bordering the Caspian Sea and in the mountains of northwestern Iran.

Humidity, fog, clouds—The relative humidity is typically low except near the coasts. The air over the Thar Desert in May, just before the beginning of the southwest monsoon, is exceedingly dry. Humidities as low as 1% have been observed which effectively "burn" any existing vegetation. Low desert humidity makes the high temperatures more endurable due to the increased evaporative cooling power of the air.

Narrow coastal regions bordering the Red Sea, Persian Gulf, and the Arabian Sea have very high dewpoints: they are extreme on the immediate shore of the Persian Gulf, where dewpoints over 85°F have been observed during July, August and September. Under these conditions, coupled with strong sunshine and Very Hot temperatures, heat stroke can be frequent. In addition, the nights are damp, sultry, and very unpleasant.

Clouds are more prevalent in the northern part of Southwestern Asia during winter accompanying the few cyclonic storms that pass through. Elsewhere, cloudiness averages a little more in summer than in winter.

Wind—The winds in this area are light during the summer, but they can be cold and blustery at times during the winter and spring, especially in the northern portion. The most hazardous winds are those associated with dust and sand storms. These can occur over most of the Arabian Peninsula and Iraq, in the dry interior basins of Iran and Turkey, and over Northwest India. Cold fronts may be preceded by hot, dry siroccos in Israel, Jordan, Syria, and Iraq. Maximum wind speeds are strong, occasionally reaching gale force.

In the Thar Desert of India and West Pakistan, strong short-lived squalls occur during the Extremely Hot period preceding the summer monsoon. These squalls produce dust clouds so thick it is sometimes dark at midday. A dust haze is prevalent throughout the period. During the dry season in Karachi (March—June) there are an average of twenty days with dust storms; Jacobabad has fifteen days, Jodhpur eleven, and Agra nine. In Iran, local winds of considerable violence are observed due to the varied relief and the intense heat and cold. Summer winds are strong, hot, and often dust or salt laden.

In the Great Nefud in Saudi Arabia, winds spring up and die down abruptly, piling sand in irregularly aligned dunes. On the southeast coast of Arabia, a nighttime wind strengthened by a land breeze may reach gale force. Along the coasts of the Red Sea, if a sea breeze exists the air is oppressively humid.

(2.) Terrain

Landforms—More than half of Southwestern Asia is plain or plateau. A major, complex mountain mass constitutes the landscape of much of Turkey and Iran.

The Saudi Arabian Peninsula, almost entirely Extremely Arid, includes areas where loose sand has been blown into ridges, some ranging to 1000 feet in height, a considerable amount of desert pavement (abrasive lava flows covering much of the more rugged highlands), and extensive salt flats located on the Persian Gulf southwest of Qatar. Mountain ranges parallel the Mediterranean Sea, the Red Sea, the Gulf of Aden and the Arabian Sea. The highest elevations, over 10,000 feet, are found in Yemen in the southwestern corner of the peninsula.

Syria is typified by rugged lava flows and sandy plains. Iraq and West Pakistan have the lowest and flattest land; delta areas include large marshy sections. Great alluvial fans have developed along the Iranian tributaries of the Tigris. Stony deserts, grey desert soils, and saline soils cover most of the Iranian desert. Shallow, stony soils over bedrock are typical in all mountains and hills throughout Southwestern Asia.

The small Arid zone in India and the Extremely Arid zone in West Pakistan have areas of shifting sand and shallow playa lakes. Large gravel fans are found at bases of high mountains in the Baluchistan regions.

Hydrology—Surface potable water is very scarce throughout this entire region. Most streams are only in existence after a rain or during the rainy season. In some regions these watercourses end in a desert or a salt lake.

The greatest water resources of Saudi Arabia exist in the Eastern Hasa and on the island of Bahrein in the Persian Gulf. At a distance of a hundred miles from the Persian Gulf Coast and parallel to it for some hundreds of miles, artesian wells can be found flowing. Large wells in the Nefud region support a considerable number of people on the surrounding land. In the Arid dune regions seepage from the high dunes may feed moisture to the hollows and in such places wells may tap a permanent water table at about thirty feet.

Horizontal wells common in Iran follow the underground water table and can collect considerable amounts of water. The Baluchistan region of West Pakistan is a land of interior drainage and withering rivers which descend from bordering mountains. The interior basins of Turkey are also regions of interior drainage.

The Tigris, Euphrates, and Indus are the only major rivers of the area. These are heavy with silt, especially during the spring when they normally cover the bordering floodplains.

Natural vegetation—The vegetation ranges from absolutely none on the salt flats of interior Turkey to the small, sparse, desert shrub common in the rest of Southwestern Asia. Short grasses which do not cover the ground are also present around the perimeter of Iran, around the Persian Gulf, and in the Tigris-Euphrates Valley. The vegetation displays a marked seasonality, depending on the precipitation pattern of the particular area.

The transition between different types of vegetation is normally gradual. One type of vegetation becomes mixed with another and gradually the second type predominates as different aridity zones are crossed. This transition is very irregular in mountainous areas such as Iran and West Pakistan.

Desert vegetation is almost entirely absent on the erg (shifting sand) desert areas of Saudi Arabia. An area of dense unhospitable vegetation exists in the Indus delta. This wilderness area consists of mud flats, tidal marshes and mangroves.

Cultural features--Most of this area is sparsely populated, with nomadism and seminomadism being common. Permanent agriculture settlements are found in the Indus, Euphrates, and Tigris river valleys and around the larger oases. There are a number of moderate-sized cities, in the hundreds of thousands population class, most of them in coastal locations. By far the largest is Karachi, capital of Pakistan, with two million inhabitants.

Transportation routes are very scarce throughout this region. The best networks of roads and railroads exist along the Mediterranean Coast, and in West Pakistan and adjacent India. Few roads cross the interior regions.

b. Semiarid environments

(1) Climate

Precipitation--The precipitation pattern of the Semiarid climate of India is very regular, almost the whole area having eight months with no more than three rainy days and four very rainy months during the summer monsoon, beginning in June. Rainfall at this time is greatest along the west coast and least north-south through the middle of the country. July is the wettest month, with around twenty-five rainy days. Another area of summer rains is the small upland Semiarid zone in Yemen, but the wettest month has only four or five rainy days.

The remaining Semiarid zones have a winter maximum of precipitation. These rains are especially heavy along the coasts of Syria, Lebanon and Israel due to orographic lifting of the air from the Mediterranean Sea. These areas may experience prolonged periods of cloudy weather with light rain during the winter months. In the higher elevations of Turkey and Iran the precipitation may be in the form of snow. In these areas the ground is commonly wet and depressions may be water covered during late winter and spring. These areas are generally dry in the summer except along the immediate coasts of the Black Sea and Caspian Sea. The small Semiarid region on the north coast of the Persian Gulf also has winter rains, but they are lighter and less regular than in the Semiarid regions to the north.

Temperature--The hottest part of Semiarid Southwestern Asia is in India where a sizable area just meets the criterion for the Extremely Hot classification, two months having mean daily maxima of 105°F or higher. The highest temperatures in India occur in May or June, just before the start of the summer monsoon. The greatest range of temperature is experienced in Iraq, where summer qualifies as Extremely Hot and winter is Cold. The Semiarid zone along the Persian Gulf Coast has high humidity as well as a Very Hot classification, presenting extremely uncomfortable conditions. The coldest part of Semiarid Southwestern Asia is the highest, in Afghanistan. This area is classified as Very Cold based on its winter; its summer temperatures may reach the 80's, but not enough for the area to be Hot.

Humidity, fog, clouds—There are a few exceptions to the usual semiarid climate relative humidity characteristics. The Persian Gulf coast and the Mediterranean coast of Turkey during the summer have high relative humidities and high dewpoints. High humidities and high temperatures are also typical of the coastal regions of India during the summer monsoon.

Except for occasional periods of dust-produced haze, the visibility during the dry season is very good. The best weather and greatest visibility over the Semiarid regions of India occur in the late spring, just before the onset of the summer monsoon. Cloudiness is maximum in summer with at least part of nearly every day overcast. Semiarid regions from the Mediterranean to the Caspian Sea have winter cloud maximum. Periods of cloudy weather with light precipitation alternate with periods of clear, cool weather and excellent visibility.

In winter in the northern Semiarid areas, cold fronts may bring strong, cold northwesterly winds. These winds may be sand or dust laden in the drier portions of Iran and Afghanistan. Dust storms also occur occasionally over the Semiarid regions in India during the dry winter and spring months.

(2.) Terrain

Landforms—India is essentially a plateau sloping down from west to east. In Afghanistan, rugged mountains reach elevations exceeding 16,000 feet. The Semiarid region bordering the Black Sea and the Caspian Sea is also mountainous but, although individual peaks exceed 16,000 feet, it is not nearly as high as Afghanistan in average elevation.

The Semiarid region along the Persian Gulf Coast is a region of low mountains and foothills which parallel the coastline. The mountains in Yemen are responsible for the Semiarid island on the Arabian Peninsula.

Much of the Semiarid Indian Plateau has a dark fertile soil. The hilly or mountainous Semiarid areas have a much coarser surface, with broken rock and rock outcrops common, especially at the higher elevations.

Hydrology—Surface streams and rivers are common in the Semiarid regions of India, crossing most of the width of that sub-continent to empty into the Bay of Bengal. These waters are likely to be polluted, especially in the heavily populated coastal regions, and purification of the water may be necessary. The largest river in this section is the Ganges which drains a large portion of Northern India. In the remaining Semiarid regions, surface potable water is scarce. Many lakes in Iran and Turkey are salt lakes and their water unpotable.

Natural vegetation—The vegetation in these areas ranges from the desert shrub in the drier areas to short, tufted grasses and open forests. The Semiarid regions of India have an open forest with thorn forests present in the drier interior sections. In Afghanistan and along the Persian Gulf Coast of Iran there are mixtures of short grasses and desert shrub. The Semiarid region joining the Black Sea and Caspian Sea has an irregular pattern of grasses, shrubs and trees. Turkey has a relatively smooth transition from the short, tufted grasses of the dry interior to the forests around its borders.

Cultural features—By far the most heavily populated Semiarid region in Southwestern Asia is in India. The vast majority of these people are farmers with the greatest populations along the coasts and in the Ganges River Valley. There are several cities with metropolitan populations in the millions, among them Delhi, Kanpur, and Hyderabad.

India has the best transportation system, with many roads and railroads crossing the country. The remaining Semiarid areas have fewer surface routes due to their mountainous terrain and less dense population. Turkey has many roads but only a few major railroads.

SOUTH-WESTERN

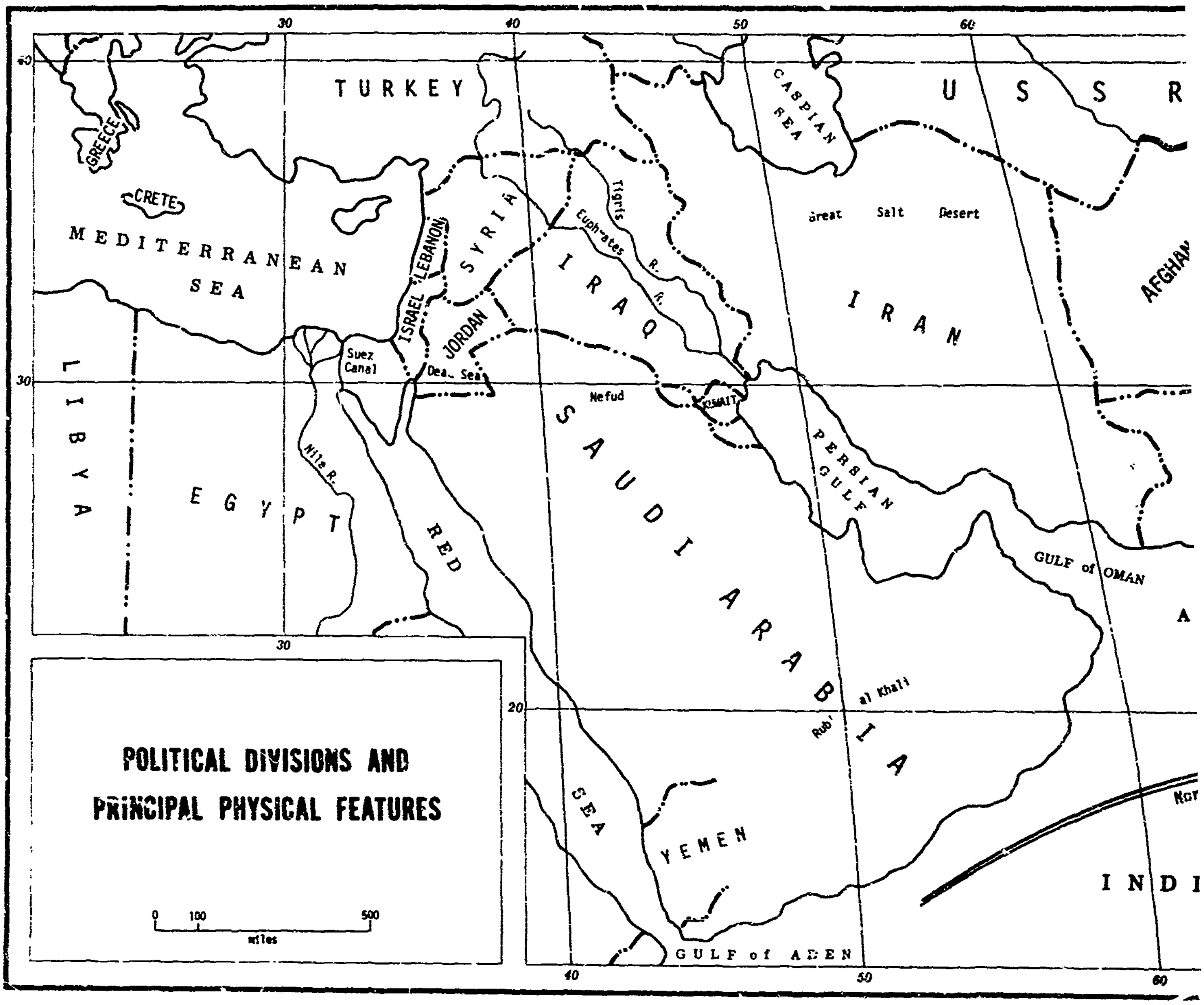
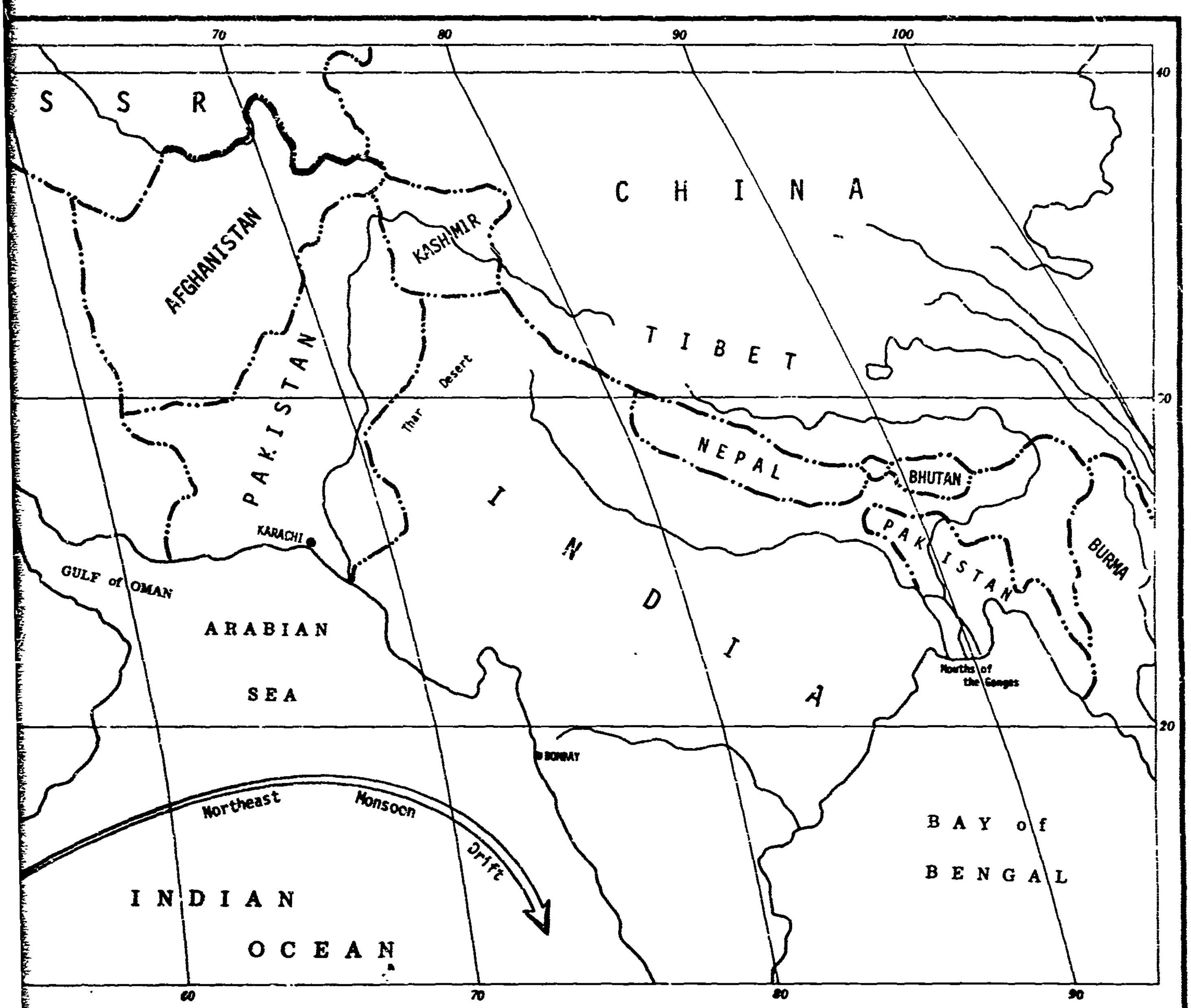


Figure 6

A.

H-WESTERN ASIA



B.

SOUTH-WESTERN A
DISTRIBUTION OF DRY CLIM

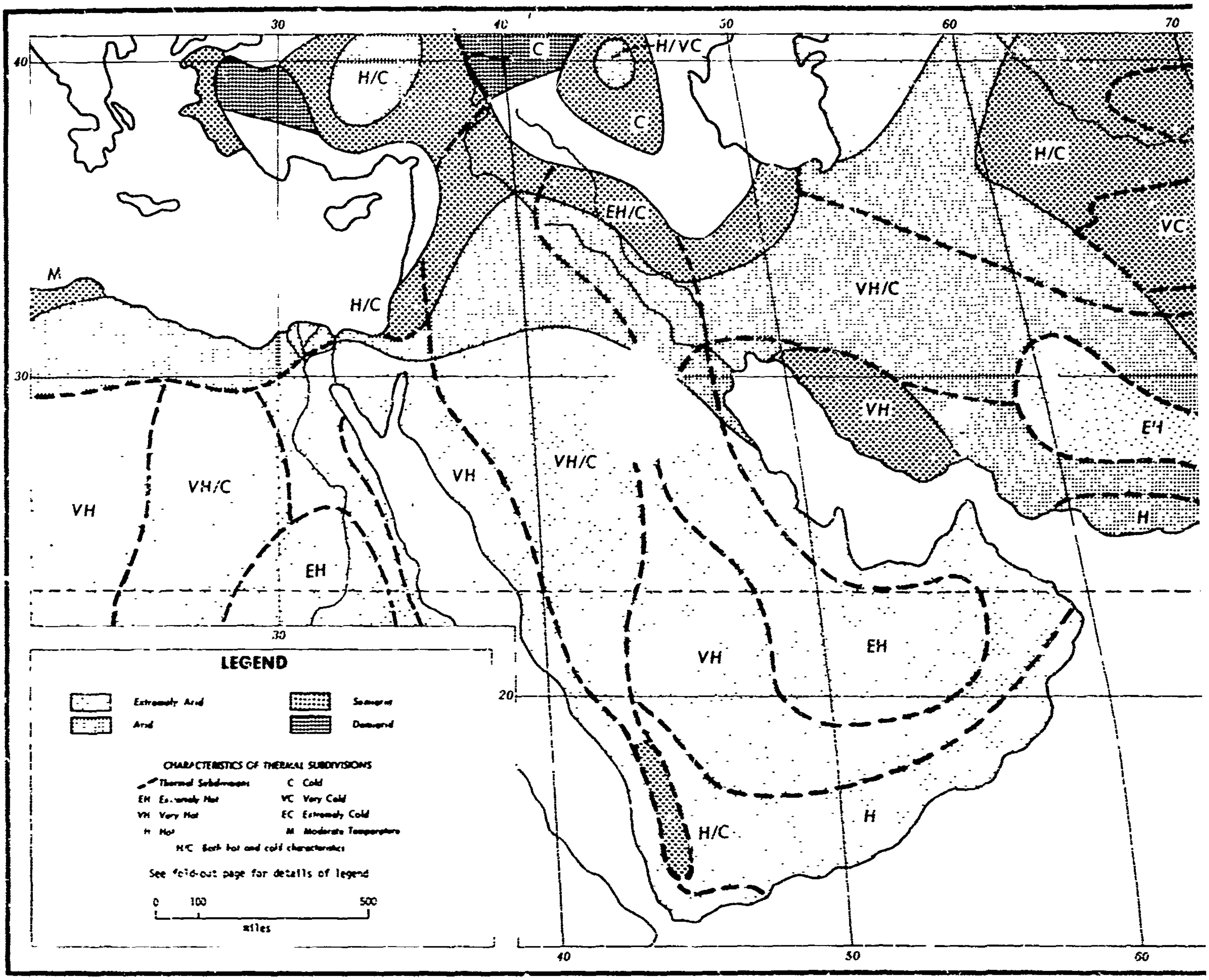
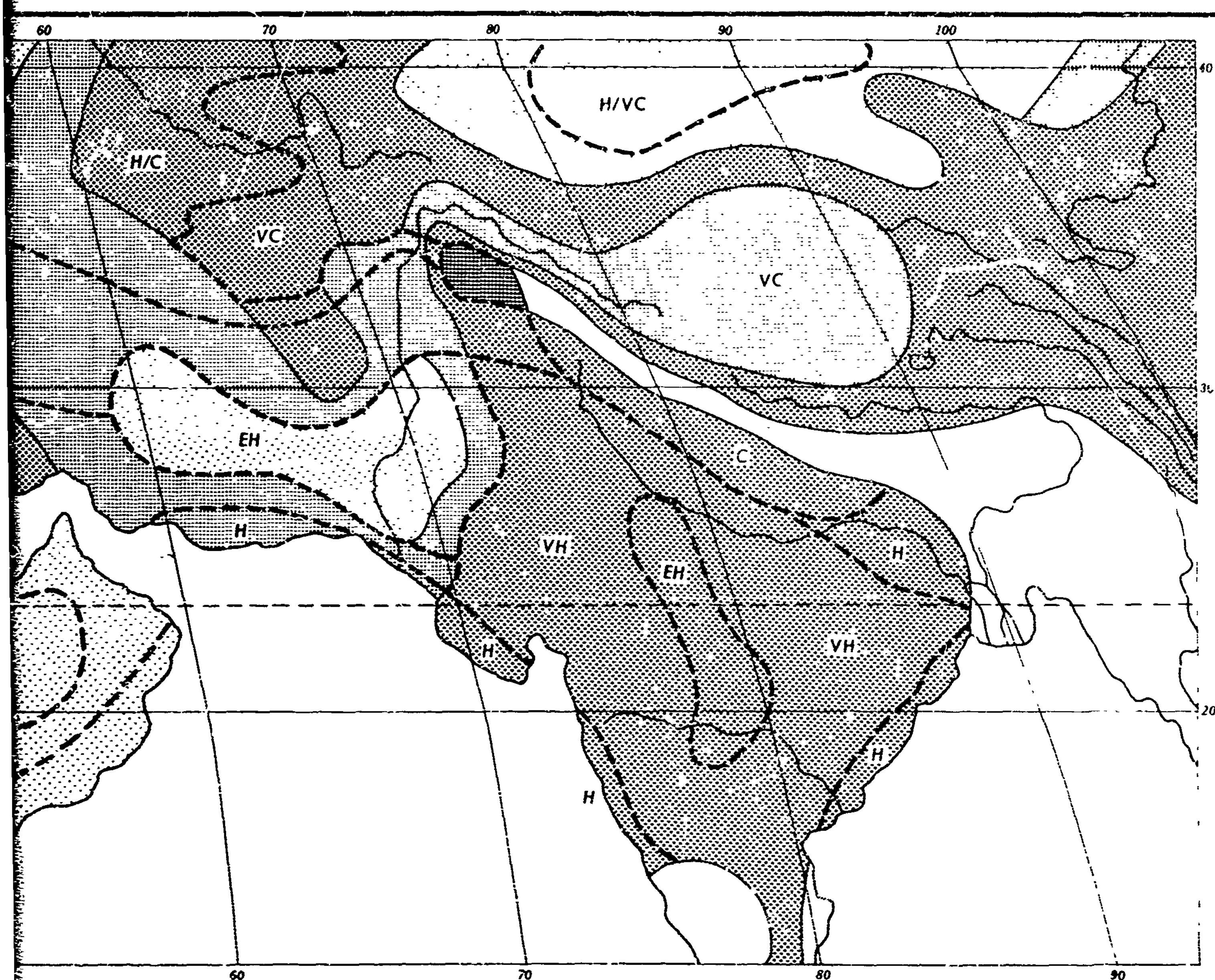


Figure 7

A.

...UTH-WESTERN ASIA
...ON OF DRY CLIMATIC TYPES



B,

3. North Africa

Arid North Africa includes more than 9% of the earth's land surface, but less than 2% of the earth's people. The region as a whole is accentuated by flat topography with large areas of sand and bare ground with little or no surface water. The world's largest sand desert, the Sahara, is Extremely Arid.

The Semiarid environments cover a relatively small area compared to the Arid environment, marking rapid transition to wet climates. Semiarid environments along the Mediterranean coast are distinctly different from those across North Central Africa. The former have winter rains in association with cyclonic storms moving eastward over the Mediterranean Sea. Here, frontal passages may result in rain showers, gusty winds and a drop in temperature; sand and dust storms may accompany the frontal passages. Prolonged cloudy weather with light rain is also possible in this area during the winter. The lower latitude region has winter drought and summer showers which develop during northward displacement of the moist intertropical convergence zone.

a. Arid environments

(1.) Climate

Precipitation—Most of the precipitation in this region is confined to a few months of the year. Precipitation is commonly sporadic and in the Extremely Arid zone it may even be non-existent for a number of years. Rain usually comes as heavy brief showers, often accompanied by winds and lightning. The sudden showers can cause local flash flooding. Heavy rains have been observed to fill wadis and are a hazard, especially on the Semiarid edge of Arid regions. These heavy showers can also swamp extensive flat areas (playas, lake beds) and stop all traffic for days, even on roads. In the Extremely Arid zone the danger from flash flooding is less serious.

The extreme northern portions of Arid climate sections may experience prolonged periods of cloudy weather with light rain or drizzle during the winter months. In the center of the Extremely Arid zone there is little systematic variation in precipitation throughout the year and one heavy shower may constitute the entire annual rainfall for the area. To the south summer showers become a greater possibility. Such showers are usually brief and confined to the late summer months.

Temperature—Except for a very narrow band in the north this area is classified as Very Hot and Extremely Hot. In the latter thermal zone, up to five months have mean daily maximum temperatures of 105°F or higher. Cloudless skies enable the intense solar radiation to raise the temperature of the bare ground to 170°F or 180°F. The highest temperatures occur during July in the flat, vegetationless zone of the Sahara. Increased summer cloudiness along the southern borders may cause an earlier temperature peak.

During the winter, frontal passages can occur in this area. They are stronger over the more northern sections where they can produce freezing temperatures. The frontal passages produce alternating periods of low and high temperatures in these northern sections. The southern portions, with fewer frontal passages, have a milder winter with no months having a mean daily minimum temperature below 45°F.

Humidity, fog, clouds—The relative humidity of this area, especially in the Extremely Arid portion, is very low. In the central Sahara the average midday relative humidity is 20—30% in winter and only 10—20% in summer. The wet-bulb temperature is often 40°F or more lower than the dry-bulb during the summer months. The relative humidity is not as low in the southern regions due to the summer rains. Very high values are found along the Atlantic Coast and fog is common, most frequently in late summer and fall. The coast from Port Etienne, Mauritania (21°N) northward may experience extensive fog, while to the south fog is usually localized. The shores of Somalia also have considerable fog during the summer. Dense fog averages one day a year (in winter) along the Suez Canal.

Summer is usually cloud free except for the southern fringes of the area which experience summer clouds and/or precipitation. As a consequence, midday radiation is intense.

Wind—The best known and potentially the most hazardous winds are those associated with dust and sand storms. In some cases the suspended sand is restricted to within a few feet of the ground and visibility at eye level is often excellent. On the other hand, blowing dust often extends to thousands of feet, commonly associated with the passage of cold fronts through northern Africa. Sandstorms of the Sahara are the most violent of any desert. The wind is not steady but comes in driving, intermittent gusts.

The northern Anglo-Egyptian Sudan has severe dust storms called "Haboobs," occurring most frequently during the summer. They are towering walls of dust rising to several thousand feet along a sharp front about fifteen miles long and advancing at about 35 mph. There may be thunder, but rain usually evaporates before reaching the ground. Another area experiencing severe sandstorms is the Somali Coast where the southwest summer monsoon induces a sand-laden sirocco wind that descends to the coast with furnace heat. This wind is often of gale force. Visibility in this area during the dry season (winter) tends to be reduced by haze from fine dust, with sandstorms adding coarser particles. In the Arabian Desert in Egypt (west of Red Sea) an early summer wind averaging 40 mph from the northwest sometimes keeps sand in the air for days.

(2.) Terrain

Landforms—Most of the land in this region is flat, gently sloping or gently rolling. The only exceptions are the low mountains in Ethiopia and the two small isolated regions in the interior. The characteristic landscape includes dunes, alluvial fans, hillocks, rock-strewn areas, dry lakes, broad flat plains, rocky escarpments, salt marshes and wadis. The color of the surface is light on plains and plateaus, darker in the few mountains. Sand dunes cover about a fifth of the area. They are widespread in the Libyan Desert, in northern Mali and Mauritania and in southern Algeria and Tunisia. The longitudinal dunes which parallel the prevailing wind in the Libyan Desert often exceed 300 feet in height and some extend unbroken for as much as seventy miles. Sand ridges 100 miles long, one half mile wide, and 100 feet high have been noted.

The Ahaggar and Tibesti Massif have deep canyons and valleys radiating outward from the central peaks. They are rugged deserts of stones, bare rocks, and plains of pebbles and gravel with volcanic cones punctuating the area. Between the Nile and the

Red Sea there is complicated relief of different sized wadis. Along the coast of Ethiopia the mountains slope steeply to the Red Sea and the area is deeply dissected by valleys and gorges. Along the Mediterranean coasts of Libya and Egypt, terraces parallel the coastline. The sand cover in this area is very thin, but it is often found blown into small hillocks around shrubs. These mounds range in height from a few inches to several meters.

Hydrology--Potable surface water is very scarce. Many stream beds and river courses contain water only after a rain or during the rainy season. In some regions these water-courses end in a desert or salt lake. Most of the lakes in this area are saline. Underground fresh water resources exist in some areas, usually on the edge or outside of the Extremely Arid regions, and wells can be dug to tap them. A large reservoir of potable underground water exists in the northern portions of the Extremely Arid zone in northwest Africa. It usually lies at considerable depths but it is within 225 feet of the surface at El Golea (31°N, 3°E). The Sahara has a scattering of wells and oases, these being more plentiful on its perimeter. The well water is often brackish, but it is rare that such water is dangerously toxic. In the northern portions of Egypt and Libya, underground water can be tapped by wells. The water near the top of the underground reservoirs is of low salinity and could be used for drinking, but it becomes more saline with pumping. At some locations only highly saline underground water can be found. Limited quantities of water can be obtained from the bottoms of wadis. Chains of oases which can supply large quantities of water stretch northward from the Sudan into Libya. West of the Nile in the desert of western Egypt there exist numerous artesian basins and considerable quantities of water are sometimes available on the floors of existing depressions.

The Nile River, subject to annual flooding of its banks, flows the breadth of the eastern portions of this area.

Natural vegetation—The density of vegetation is closely related to the degree of aridity. The vegetation ranges from the very sparse, drought resisting forms on most of the Extremely Arid regions to a few small leafed or thorny scrubs in the Arid regions.

In the Extremely Arid regions and along the interior borders of the Arid zones the sparse vegetation is of two types:

(1) Annuals sprout after rain showers and complete their growth in a very short growing season. This rapid growth has been observed to change the color of the ground to green overnight.

(2) Perennials (short plants), often thorn covered or with small leaves, grow in wadis or depressions and get a continuous water supply from the subsurface by means of long tap roots.

Plants growing in this region are individual plants rather than part of a plant community. In the outer regions of the Arid zones the vegetation is irregular with very open, hard grasses and scrubs. The scrubs are often thorn covered. This type of vegetation also forms a continuous, narrow belt along the Atlantic coast. Wadis are often occupied by dense thorn scrub or thorn forest. The thorny scrubs impede walking, and the barbs and spines of some species are toxic.

The Nile river valley, lying largely within the Extremely Arid zone, stands out as a green strip across the desert. Date palm and other agricultural crops are supported in this narrow band. Oases can also show an increase in vegetation. In the larger oases a closed canopy forest is possible, but the trees are very low growing.

In the following areas the desert vegetation is largely or entirely absent:

(1) Eastern Mauritania.

(2) Northern Niger, Western Libya, and Eastern Algeria.

(3) Northwestern Sudan and Western Egypt.

Although desert plants which produce edible grains or fruits are not extensive, they could provide survival nourishment where available.

Cultural features--This region is sparsely populated. Cities are confined to coasts and the Nile Valley. Elsewhere there are only very widely separated oasis communities. Cairo and Alexandria are the only big cities, each with population in the millions. Roads are the only surface transportation routes in this area. They are usually not surfaced and in some areas are merely caravan trails. Most roads cross the area from north to south.

b. Semiarid environments

(1.) Climate

Precipitation--The nature and time of occurrence of precipitation is the main distinguishing climatic characteristic between the Semiarid zones in the north and those in the south. The winter precipitation in the north may be in the form of heavy brief showers produced by a frontal passage, or as extended periods of low clouds and drizzle covering most of the area. The showers can produce localized flash flooding, especially in the hilly coastal regions of Morocco and Algeria. This zone has an average of five to ten rainy days per month from November through March. The Demiarid fringe has an average of four to six rainy days per month from October through April.

The southern Semiarid zone has a summer rainfall maximum, with up to twenty rainy days in the wettest month. The degree of aridity is the complement of the length of time the moist, showery intertropical convergence zone lies over a region in its movement north and then south during the summer season. Over the extreme southern portions of the region this movement north and south during the summer produces two peaks of rainy days, the first during early summer and the second during early fall. Toward the northern desert regions there is only one maximum occurring during late summer.

Temperature--Temperatures in the Semiarid zones are higher in the area bordering the Sahara on the south than in the north, and show less variation from season to season and day to day (especially during the winter). This lack of variation in temperature is caused by the proximity of the Semiarid zones to the equator, far removed from the disturbing effects of the winter Mediterranean cyclones.

The southern area has either a Very Hot or Extremely Hot thermal classification. The highest readings are in areas bordering the Arid regions to the north. From four to eight months are observed with mean daily maximum temperatures above 95°F. The maximum temperatures are observed just prior to the beginning of the summer showers which usually begin sometime in June.

Temperatures in the Semiarid and Demiarid regions near the Mediterranean Sea reflect water and elevation influence. Coastal locations have Moderate temperatures, with neither hot summers nor cold winters. In the mountains, summers are Hot and winters may be Cold.

Humidity, fog, clouds—The relative humidity in the Demiarid and Semiarid zones is low during the winter in the south and summer in the north. It is the lowest in the regions bordering the Arid zones. Dryness is also the trademark of the hot sirocco winds. Cloudiness has the same seasonal pattern, greater in winter near the Mediterranean (cyclonic storm cloudiness) and greater in summer in North Central Africa (convective clouds).

Fog occasionally occurs along the Atlantic Coast of southern Morocco.

Wind—Occasional strong winds are associated with the passage of fronts in the northern areas. These strong winds can carry dust up thousands of feet. They are more common during the autumn and spring. Dust-laden winds may also exist ahead of the cold front when hot, dry southerly winds blow from the desert areas of the Sahara, the Khamsin or sirocco. Due to the fine dust, vehicles often must use lights at midday. The winds may continue for two to three days.

In the Semiarid region in the south during winter, a frontal passage may bring originally cold air from the north across the Sahara with considerable fine dust. Smoke added from local brush fires produces a haze which may extend to 15,000 feet. This condition is known as the Harmattan.

(2.) Terrain

Landforms—The Semiarid and Demiarid regions bordering the Mediterranean are predominantly hilly or mountainous, especially in Morocco where alluvial fans stretch inland from the Atlas mountains. An exception is the small Semiarid region around Tarabulus (Tripolis), Libya, where the flat desert landscape meets the Mediterranean.

The Semiarid band to the south of the Sahara is a region of low hills. Further to the east in Ethiopia the Semiarid zone embraces the lower elevations of relatively rugged mountains.

Hydrology—Potable water is available from streams and fresh water lakes during the rainy season. During the dry season many of the streams are dry but water may still be obtained by digging in the dry stream beds, especially in the mountainous areas. Lake Chad is a large, permanent, fresh water lake, an unusual occurrence in this area.

Natural vegetation—The vegetation in these Semiarid areas reflects the transition zone between the desert vegetation of the Extremely Arid zones and that of the adjacent lands of greater rainfall. The southern Semiarid zone has a grass cover and a few trees although a closed canopy is not usually achieved, an open stand of trees being

more commonly observed. The grasses are taller in the eastern portions of this area. The patches of open woodland contain deciduous trees which do not generally exceed thirty to forty feet in height. The grasses tend to become more dominant in the drier sections. Lake Chad interrupts this pattern with swamps occupied by tall reeds, bulrushes and wild millets which grow fifteen to twenty feet tall and form inextricable masses of floating vegetation.

The semiarid zones along the Mediterranean Coast have a predominantly low grass cover with a trend towards scrubs and short trees as the immediate coast is approached.

Cultural features—Population density reaches maximum in Africa in the Semiarid and Demiarid climates. There are numerous towns and a few major cities with increasingly modern facilities. Outside the cities, transportation routes are mainly a few unimproved roads and a few railroad lines, both being most common in Morocco and along the Algerian Coast.

NORTHERN AFR

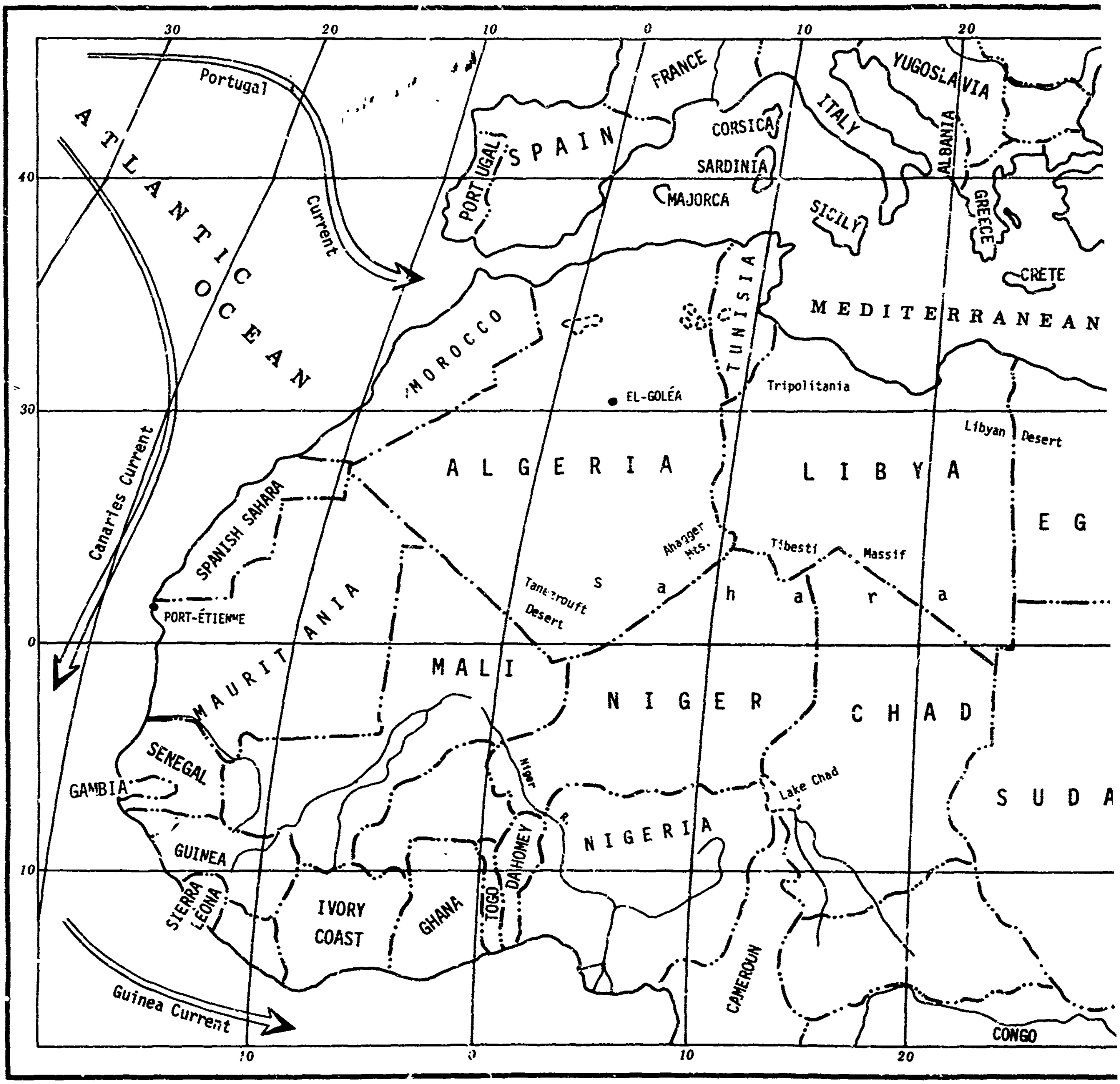
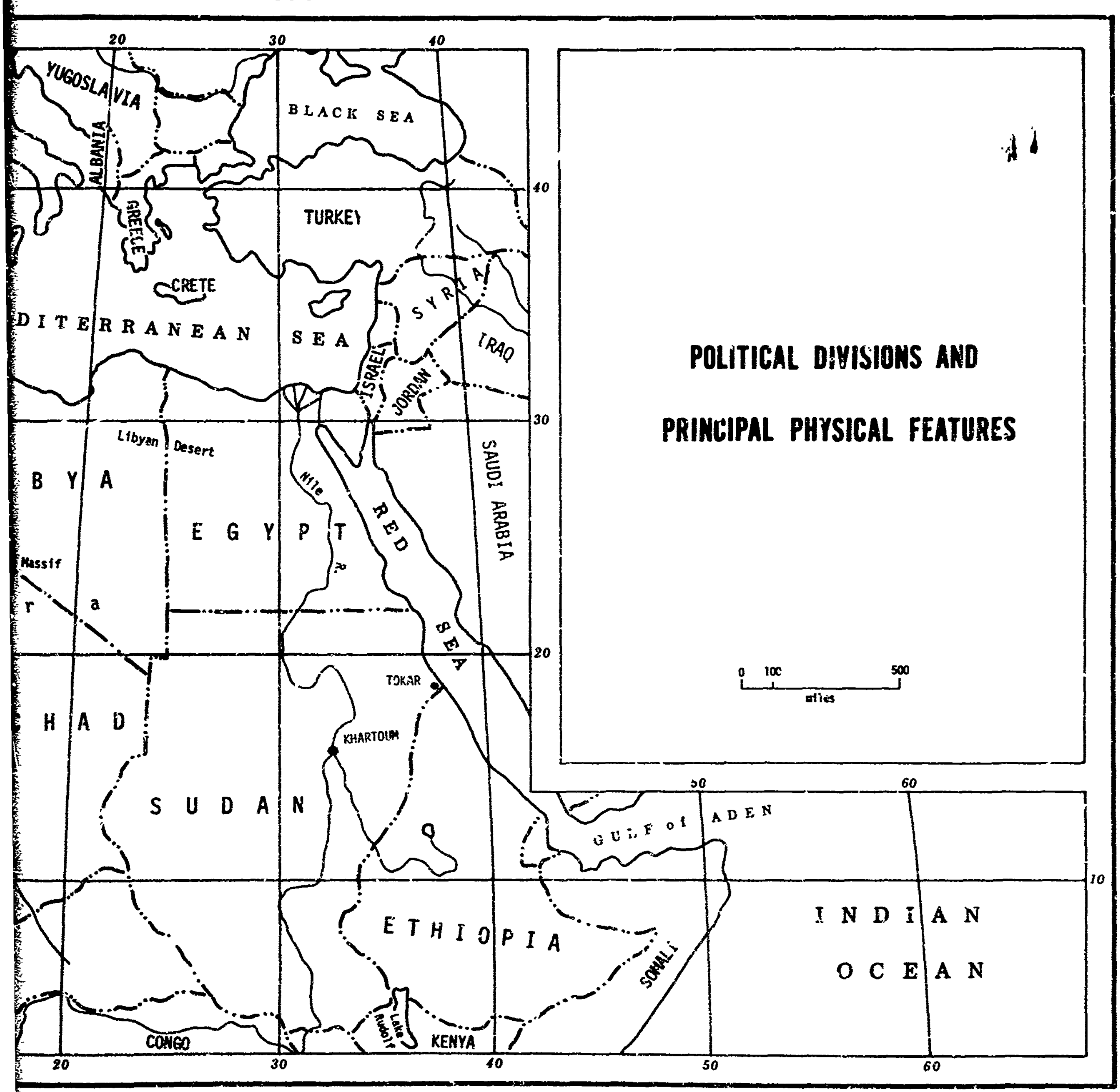


Figure 8

A.

ORTHERN AFRICA



B.

NORTHERN AF
DISTRIBUTION OF DRY C

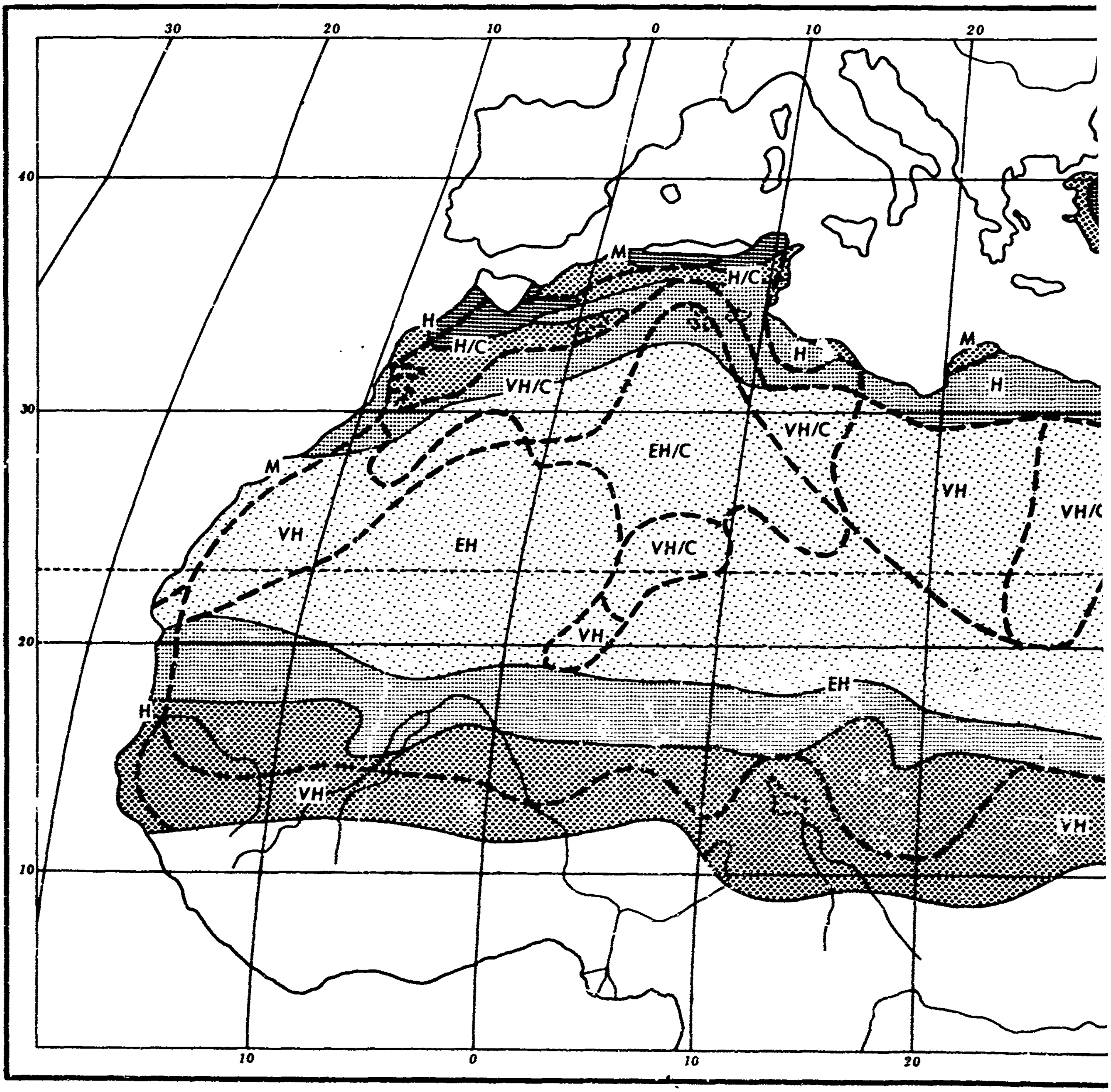
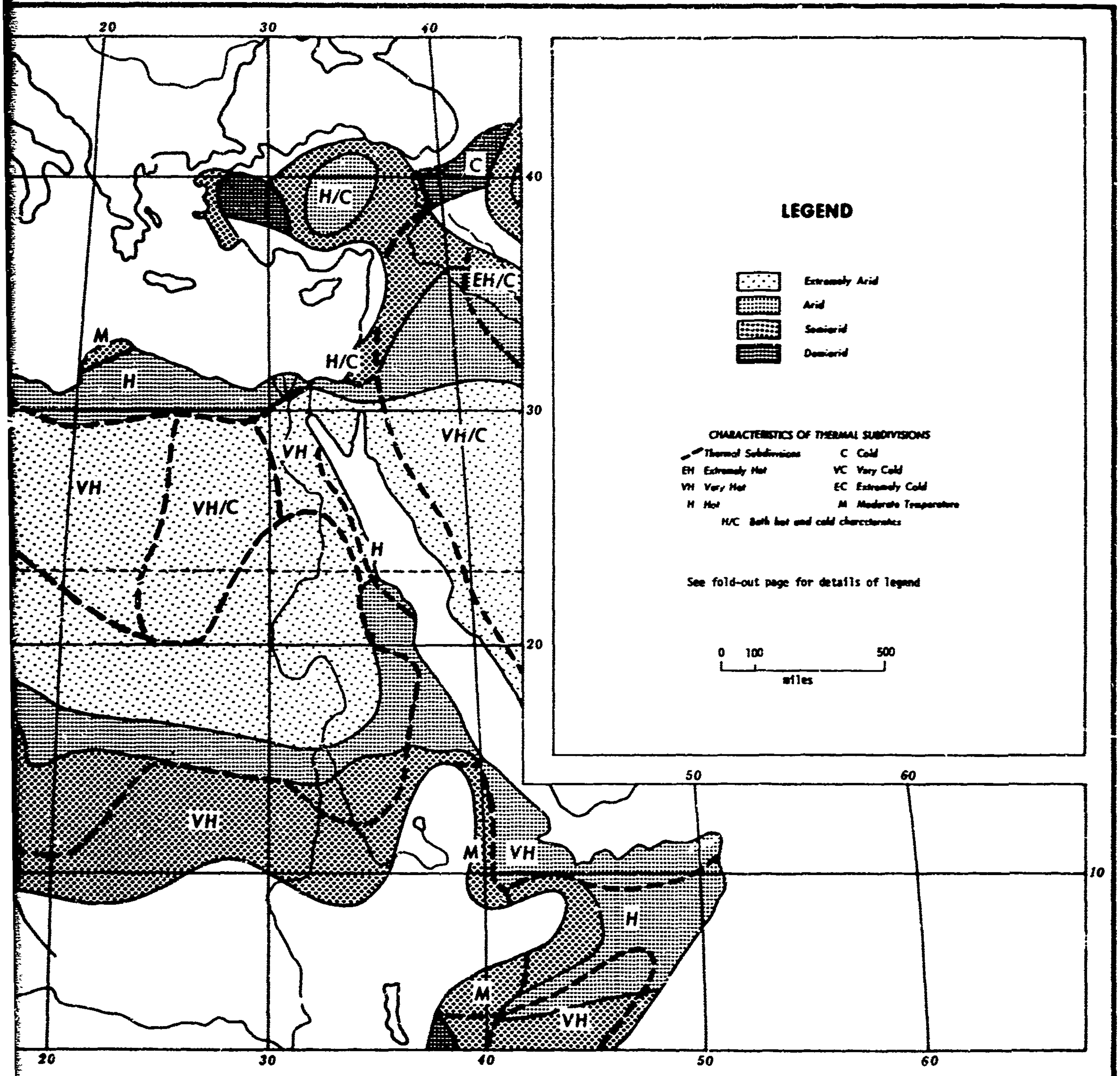


Figure 9

A.

RTHERN AFRICA
N OF DRY CLIMATIC TYPES



B.

4. South Africa

Somewhat more than half of southern Africa and the island of Madagascar are arid and semiarid. In most of this region rainfall is concentrated in the summer months (November—April) when the intertropical convergence zone is displaced south from the equator. Rains during this period are appreciable, with an average of fifteen to twenty rainy days per month in limited areas of the Semiarid and Demiarid climates near the equator. Along the southern coast of dry South Africa, the winter months have as many rainy days as summer, generally no more than six days in any month.

The only Extremely Arid zone is a narrow strip along the southwest coast. The absence of large Extremely Arid areas reflects the relatively small size of this land mass and the absence of a large land area at higher latitudes. The warm season precipitation maximum is consistent with the absence of Extremely Hot areas; in fact only two small Very Hot zones are found in the entire region.

a. Arid environments

(1.) Climate

Precipitation—The Extremely Arid and the Arid zones north of 30°S latitude have a summer maximum of rainy days. These areas are very dry during the winter season with the months June through August commonly having an average of zero rainy days. Over the extreme southern tip of Africa the maximum rainfall occurs during the winter. The greatest variability of rainfall from year to year exists in the Extremely Arid zone of the southwest coast where a departure of over 40% from the annual mean is common.

Temperature—The temperatures in this region do not display the extremes of heat and cold often found in arid environments. Even in the Extremely Arid zone, a Moderate thermal zone exists. In the Hot thermal zones of the Extremely Arid region, the number of months with mean maximum temperature 85—94°F varies from two to five. However, most sections of the Arid regions, being situated inland, typically have four to six such months while near the Kalahari Desert the number is more commonly seven. Noteworthy characteristics of the temperature regimes of this general area are the small variations of temperature from day to day and year to year.

Humidity, fog, clouds—Fog and high humidity are common along the coast, especially during the summer season. The fog is dense enough to wet ground. Inland, seventy miles or more, fog is rare and the relative humidity is characteristically lower.

The amount of cloudiness follows the pattern of precipitation. Cloudiness is at maximum during the summer in the north while the clearest periods are just prior to and just after the rainy period in September and May. The region further to the south has a maximum of cloudiness during winter (June—August).

Wind—Destructive winds are absent from the region. Summer convective showers in the northern sections are sometimes accompanied by brief gusty winds.

(2.) Terrain

Landforms—The coastal plain averages 50 to 100 miles wide with mountains rising steeply from it to the interior. Along the coastal side of the Kalahari

are the Awas and Karas mountains. These ranges separate the Namib from the Kalahari Desert. The soil along the coast is sand. The mountains between the coast and the Kalahari are barren. The rest of the area is covered with calcrete, a hardened brown soil beneath a thin layer of sand.

Hydrology—The major perennial rivers of the area are the Cunene and the Orange, both located in the Kalahari. In the Extremely Arid area is the Molopo River basin. This river rarely contains running water. Salt flats, common in the Kalahari desert, are covered by shallow layers of water after occasional rains.

Natural vegetation—Most of the land supports tufted grasses referred to collectively as the "Sand Veld." These grasses are interspersed with patches of tree or scrub savanna. Typical of arid climates, the grasses are xerophytic (drought resistant) and the trees and scrubs often thorn covered.

Cultural features—This area is sparsely populated, with its few inhabitants typically primitive and tribal. One tribe of the Bushmen Hotentots is considered by anthropologists to be one of the earth's most primitive people. Major transportation routes are limited to one railroad and a few motorable roads.

b. Semiarid environments

(1.) Climate

Precipitation—The summer rains are abundant, with number of rainy days per month increasing rapidly to maxima of fifteen to twenty during November through April. In Madagascar, orographic lifting of air borne by southeast winds contributes to summer rain. These summer rains occur mainly as showers and thunderstorms. In the autumn (March—June) the rains are mostly confined to the east coast sections of South Africa. In the northern sections, winter is very dry with no rainy days during June through August. Toward the south and southeast, the winter precipitation gradually increases so that the southeast coast of South Africa and the Semiarid regions in Madagascar have few areas with zero rainy days during the winter. The winter rains in the south are relatively light in intensity, but may last for days.

Temperature—Throughout this area topography has an important effect on temperature. The high mountains have cool temperatures throughout the year, whereas the east coast and the low lying valleys have warm temperatures most of the year. In the winter, temperatures in the Cold highlands are low enough to produce frost, but the mean daily minimum temperature is never colder than 25°F.

The number of months with Hot mean maximum temperatures 85—94°F, increases from two to three along the northwest boundary of the Semiarid region to eight or nine along the southeast coast. The west coast of Madagascar, sheltered from the moist southeasterly winds by interior mountains, also has eight or nine such months. The northwest coast of the island has maximum temperatures in this range every month of the year.

Humidity, fog, clouds—Highest humidities occur during the rain season (summer in the north, winter in the south) with the highest values along the coastal sections. The high relative humidities at summer temperatures typical in the north result in sultry, unpleasant conditions. Cloudiness also follows the precipitation regime with overcast

or near overcast conditions prevailing during seasons of maximum rainfall. On the east coast of South Africa fog and stratiform clouds are prevalent during the summer.

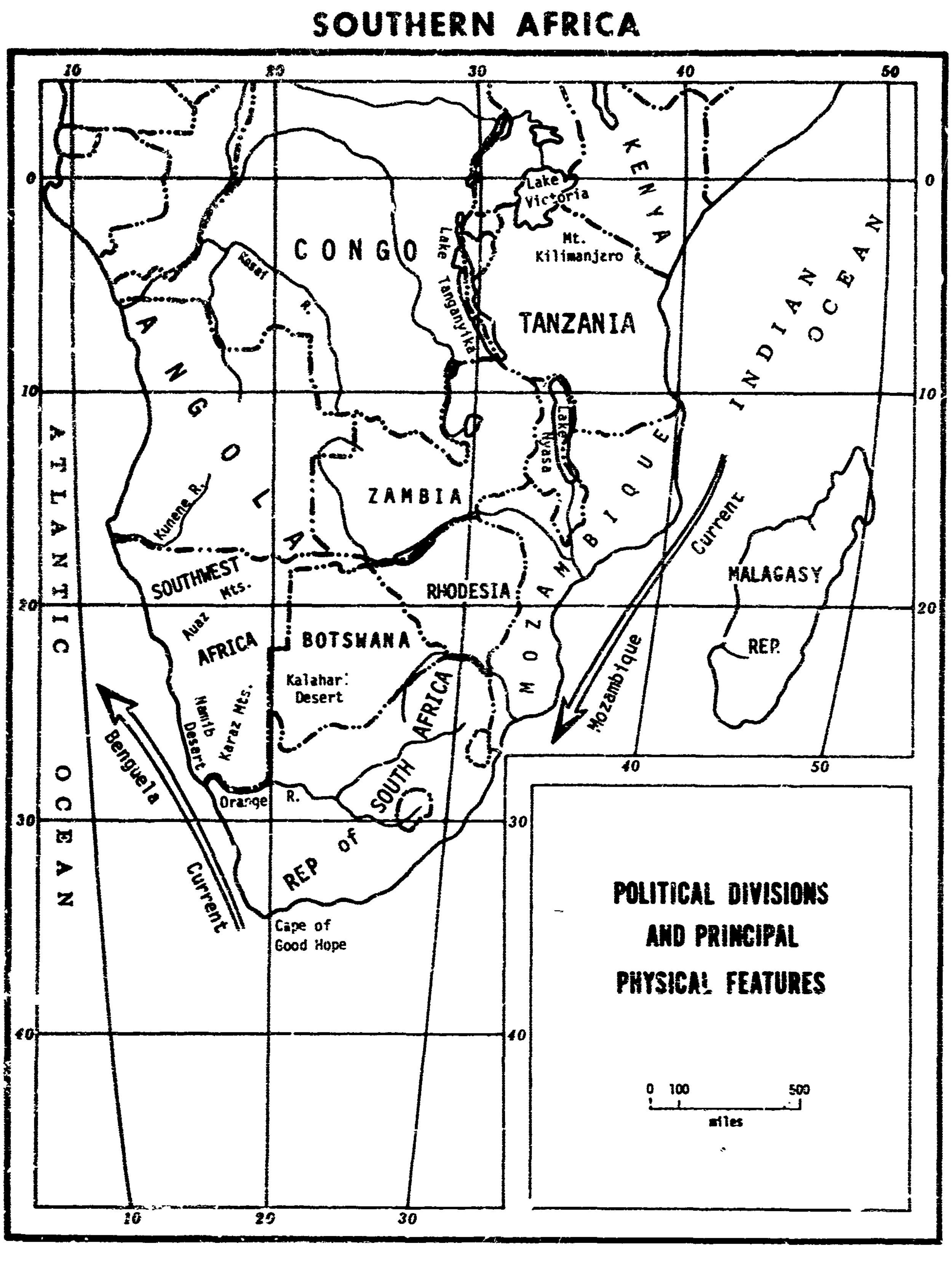
(2.) Terrain

Landforms—The average elevation of South Central Africa is 3000 to 5000 feet above sea level. Included in this general area are the plains, hills and mountains of the southern and western sections. A mountain range roughly parallels the southeast coast. This range includes some impressive peaks such as Mount Kilimanjaro at 19,590 feet.

Hydrology—By far the largest lake in this area is Lake Nyasa at an elevation of 1,550 feet. This lake covers more than 8,000 square miles. A large number of rivers cross the Semiarid portions of South Africa. Many of these are tributaries to the Zambezi and the Limpopo Rivers which empty into the Indian Ocean. These rivers reach their greatest levels during the period of summer rains, but they carry some water at all times of the year.

Natural vegetation—This entire area is essentially a grassland. In the central portions of the Semiarid regions of South Africa scrub and thorn bushes are found along with the grass. In the more arid regions the grass is found as tufts interspersed with bare ground. Trees are more common on the higher slopes. In the south, just inland from the east coast, heavy grasslands are found.

Cultural features—The population is relatively sparse with the largest concentrations of people found near the southeast coast of South Africa. Due to the presence of industry, mining, and farming in the southeast corner of South Africa, this area has the best surface transportation routes. Motorable roads and railroads are common throughout the area. To the north of this area and in Madagascar, surface routes are limited to a few roads and even fewer railroads.



SOUTHERN AFRICA
CONGO
KENYA
Lake Victoria
Mt. Kilimanjaro
Lake Tanganyika
TANZANIA
INDIAN OCEAN
ANGOLA
Kasai R.
ATLANTIC OCEAN
Kunene R.
ZAMBIA
Lake Nyasa
MOZAMBIQUE
Mozambique Current
MALAGASY REP.
SOUTHWEST AFRICA
Auaz Mts.
RHODESIA
BOTSWANA
Kalahari Desert
Namib Desert
Karaz Mts.
Benguela Current
Orange R.
REP of SOUTH AFRICA
Cape of Good Hope
POLITICAL DIVISIONS AND PRINCIPAL PHYSICAL FEATURES
0 100 500
miles

Figure 10

SOUTHERN AFRICA
DISTRIBUTION OF DRY CLIMATIC TYPES

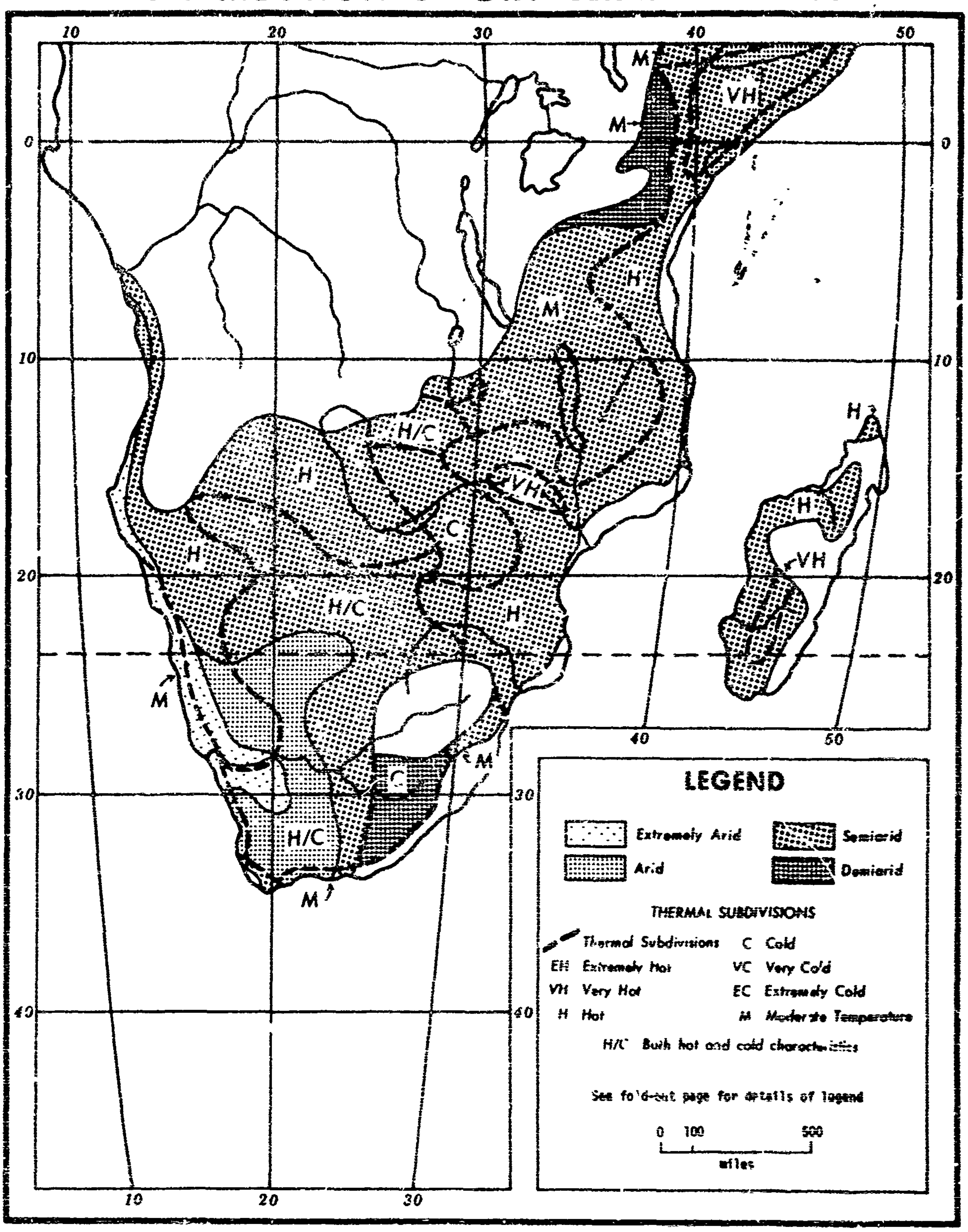


Figure 11

5. Australia

Australia is the world's driest continent. Ninety percent of its three million square miles meets the qualifications for aridity in one way or another, with slightly more than half the area of the continent being classified as Arid or Extremely Arid. This high proportion of dry climates results from the fact that almost all of Australia lies within the sub-tropics in which, throughout the world, atmospheric activity is frequently unfavorable to the formation of rain. The wettest part of the continent is in and seaward of the Eastern Highlands, where orographic lifting assists atmospheric processes in releasing moisture from inflowing maritime air.

In approximately the northern half of Australia, rainfall and rainy days are concentrated in the summer months (December—March) in association with intertropical convergence. The south gets its rain mostly from extratropical cyclones in winter (June—September). Summer rain is less reliable and more likely than winter rain to fall in heavy showers. Snowfall is rare in the arid and semiarid climates of Australia.

Australia is unique among the Southern Hemisphere continents in the extent of Very Hot thermal characteristics. Nearly two-thirds of its arid and semiarid climates have at least two months when daily maximum temperatures of 95°F and above are common. Further, although it is a sub-tropic continent, more than one-third of Australia has Cold thermal characteristics. Extremes of heat and cold do not occur, however, as they do on the larger continents of the world.

Probably because a large proportion of the continent has a dry climate, Australia's population density is the lowest in the world. The bulk of its eleven million inhabitants live on the less than 10% of the land that is not arid or semiarid or mountainous.

a. Arid environments

(1.) Climate

Precipitation—In the Extremely Arid region, the ten to twelve driest months generally have one rainy day each. Few if any months have no rainy days. In contrast, much of the Arid region and even much of the Semiarid have several extremely dry months with no rainy days, but the remaining months of the year have up to three or more rainy days per month commensurate with the Arid and Semiarid climate definitions. Toward the north in the Arid region, the summer months have noticeably more rainy days than the rest of the year. To the south, distribution of rainy days is more even through the year with a slight maximum in winter months.

Temperature—The effect of elevation on temperature is seen in the extent of Cold thermal characteristics as close to the equator as 22°S within the Arid region. But nowhere in Australia does the temperature drop very much below freezing. Absolute minima at the coldest stations are generally in the low twenties.

The two-thirds of Australia's Arid and Extremely Arid regions that are Very Hot experience from two to six months with mean daily maximum temperatures between 95°F and 105°F. Most Very Hot months will have at least one day with maximum temperature in the 105—115°F range and absolute maximum in the 115—125°F range. At Marble, on the edge of the Great Sandy Desert (elevation 600 feet), maximum of 100°F or over have been recorded on 161 consecutive days, with an absolute maximum of 121°F.

Humidity, fog, clouds—Relative humidity is low in the deserts of Australia, where it is often under 20% on afternoons with Very Hot temperatures. The portions of the Arid region having highest humidities are the south coast in its entirety and the west coast in the vicinity of Shark Bay. Both coastal strips experience relative humidities near 50% at mid-afternoon throughout the year. Fog is rare to non-existent in Australia's Arid climates, even along the coasts. Cloudiness generally follows the same regime as precipitation, maximum in summer in the north and in winter in the south, but is never a serious or continuing problem. Total hours of sunshine exceed 3200 annually in the middle of the continent, decreasing toward all coasts. Solar radiation is very strong, particularly in the northern part of the Arid region in summer when the noon sun is almost directly overhead.

Wind—Destructive winds are infrequent in Australia, particularly in the interior. Occasionally a tropical storm known as Willy Willy, similar to a West Indian hurricane or a Pacific typhoon, will move southwestward along the northwest coast of Australia and may curve to the southeast and move inland. Southern Australia sometimes experiences hot, dry, dusty winds blowing from the north out of the interior deserts. These appear to be more uncomfortable than damaging.

(2.) Terrain

Landforms—The largest continuous structural feature in Australia is the Western Plateau which extends from near the west coast to about 135°E. This plateau, ranging from 600 to 2000 feet above sea level, is interrupted by isolated highlands such as the MacDonnell and Musgrave Ranges, which rise to near 5000 feet, and the Hamersley Range, just exceeding 4000 feet at its highest point. The Stirling Range, although less than 3700 feet high, has a very rough and jagged profile. Some 60% of the Western Plateau surface is sand. Sand ridges are well developed in the Great Sandy Desert and Simpson Desert, tending generally northwest to southeast. The largest ridges are about 100 feet high, 1000 feet wide, and 130 miles long. The sand ridges and sand hills of the Great Victoria Desert are scattered throughout what is otherwise generally flat country. The ridges are short and irregular, and are oriented in east-west alignment for the most part. The difficulties of crossing this desert are less than for other Australian deserts. In the southwest, salt lakes and saline depressions dominate a 100,000 square mile area.

East of the plateau is the Great Artesian Basin which includes the Lake Eyre Depression, thirty-eight feet below sea level. Nearly separated from the Great Artesian Basin by the Flinders Range and the Broken Hill Plateau are the Basins of the Murray and Darling rivers. Except for the western portion of the Great Artesian Basin, silt and alluvium are more common surface materials than sand. The 4000 square miles of the Lake Eyre region are covered with one to two feet of salt.

Hydrology—The temporal hydrological features of much of the continent of Australia reflect the extent of aridity. There are no large inland seas or lakes. The floors of the numerous depressions are best described as dry, salty flats most of the time, including even those of Lakes Eyre and Torrens which are 115 and 130 miles long, respectively. These contain water occasionally, usually only for short periods. Only the Murray-Darling river system, originating in the Great Dividing Range where precipitation is substantial, maintains permanent flow through the Arid region. In

the central Australian deserts, "rivers" such as the Finke, Diamantina, and Barcoo flow only once in several years.

The Great Artesian Basin is an important source of underground water, which is found at depths varying from 10 to 6000 feet. The temperatures of these water reserves vary from 75°F to 212°F.

Natural vegetation—In the core areas of sandy deserts (the Great Sandy, Gibson, Great Victoria, Arunta, and Simpson) the most frequently observed vegetation is the porcupine grass or spinifex. This plant is known for its sharp-edged, finely pointed leaves which can cause deep cuts upon contact. Interspersed with distinct areas of spinifex are areas of semi-desert shrub.

Cultural features—There are no large population centers anywhere in arid Australia and the relatively few small centers are located mostly near the margins of the extensive Arid-Extremely Arid region. Tens of thousands of square miles in the Great Sandy, Gibson, and Great Victoria Deserts are void of permanent habitation. In these deserts the road network is skeletal and there are no through highways. The rail network is exceedingly sparse. Air transportation is very important in most of interior Australia. Radio is the only widely used communications medium.

b. Semiarid environments

(1.) Climate

Precipitation—The two distinct regimes, summer rain in the north and winter rain in the south, are considerably more pronounced in the semiarid climates than in the arid. Near the north coast the one or two wettest months in the Semiarid region have averages of more than twenty rainy days per month. The driest two or three months are extremely dry, often with no rainy days. In the south, the difference between the wet and dry seasons is not as sharp. The southwest Semiarid area has one to three rainy days per summer month and ten to twelve per winter month. The southeast Demiarid area has one to three rainy days per summer month and four to six per winter month.

Temperature—Coastal as well as elevation influence on temperature is evident in Australia's semiarid climates. In the north, along the coast and in the Eastern Highlands, as many as twelve months may be Hot with daily maximum temperatures in the upper 80's and low 90's, but temperatures over 100°F are infrequent. However, personal discomfort may be greater than in the interior of the Semiarid region or in arid climates because of higher relative humidity. The Very Hot Semiarid interior is like the Arid region, with two to six months of daily maximum temperatures in the 90's and absolute maxima in the 100—115°F range. Two or more months should be quite comfortable, with afternoon temperatures in the 70's and nights in the 50's. Below-freezing temperatures in Australia's Semiarid climate are confined to the higher elevations of the east and the Murray-Darling Basin away from the southeast coast.

Humidity, fog, clouds—Highest humidities in Australia's arid and semiarid climates occur close to the coast. Mid-afternoon averages near the north coast in summer may run to an uncomfortable 70% when combined with high temperatures. Following the precipitation regimes, cloudiness is maximum in northern Australia during the summer and in southwestern and southeastern Australia in the winter. Sunshine can be very intense in November through January in the Semiarid region.

Wind—Occasional tropical storms affect the northwest and northeast coastal sections of Semiarid climate. Whirlwinds and tornadoes occur in the southeastern part of Australia, particularly during the summer, but the associated winds are much less violent than those in the United States.

(2.) Terrain

Landforms—Semiarid and Demiarid regions are mainly coastal plains, low inland plateaus, and the eastern highlands. The greatest restrictions to mobility are in the latter. In the Australian Alps the general altitude is frequently above 3000 feet and the highest peaks exceed 7000 feet.

Hydrology—Streams are far more numerous in the Semiarid region of eastern Australia than anywhere else in the dry part of the continent. These are fed by the abundant rains of the wet season, particularly those which fall in the Eastern Highlands. The Murray-Darling system is the only significant river system on the entire continent. Flow in these rivers varies greatly from well over the average of 70,000 cubic feet per second to so little that its mid-course source springs are easily visible.

Natural vegetation—A zone of thorn tree-desert grass savanna borders the core desert regions on the west, north, and east, extending to the Great Dividing range in the east, the coast in the west and the tropical semi-evergreen and deciduous forest in the north.

Mallee scrub, often six to eight feet in height, characterizes the dry side of the forests in the southwestern and southeastern Australia. The predominant color of the leaves is grey-green and many species emit a pungent odor.

Cultural features—Towns are considerably more numerous in Australia's Semiarid climate than in the arid regions, and the continent's third-largest city, Adelaide, is in the Demiarid region. Rail and highway systems extend into the Semiarid region from the populous adjacent rainier districts, particularly the southeast coast, which is a center of industry and commerce. Radio is a prime means of private as well as mass communication. Telephone and telegraph lines are considerably more prevalent than in arid regions.

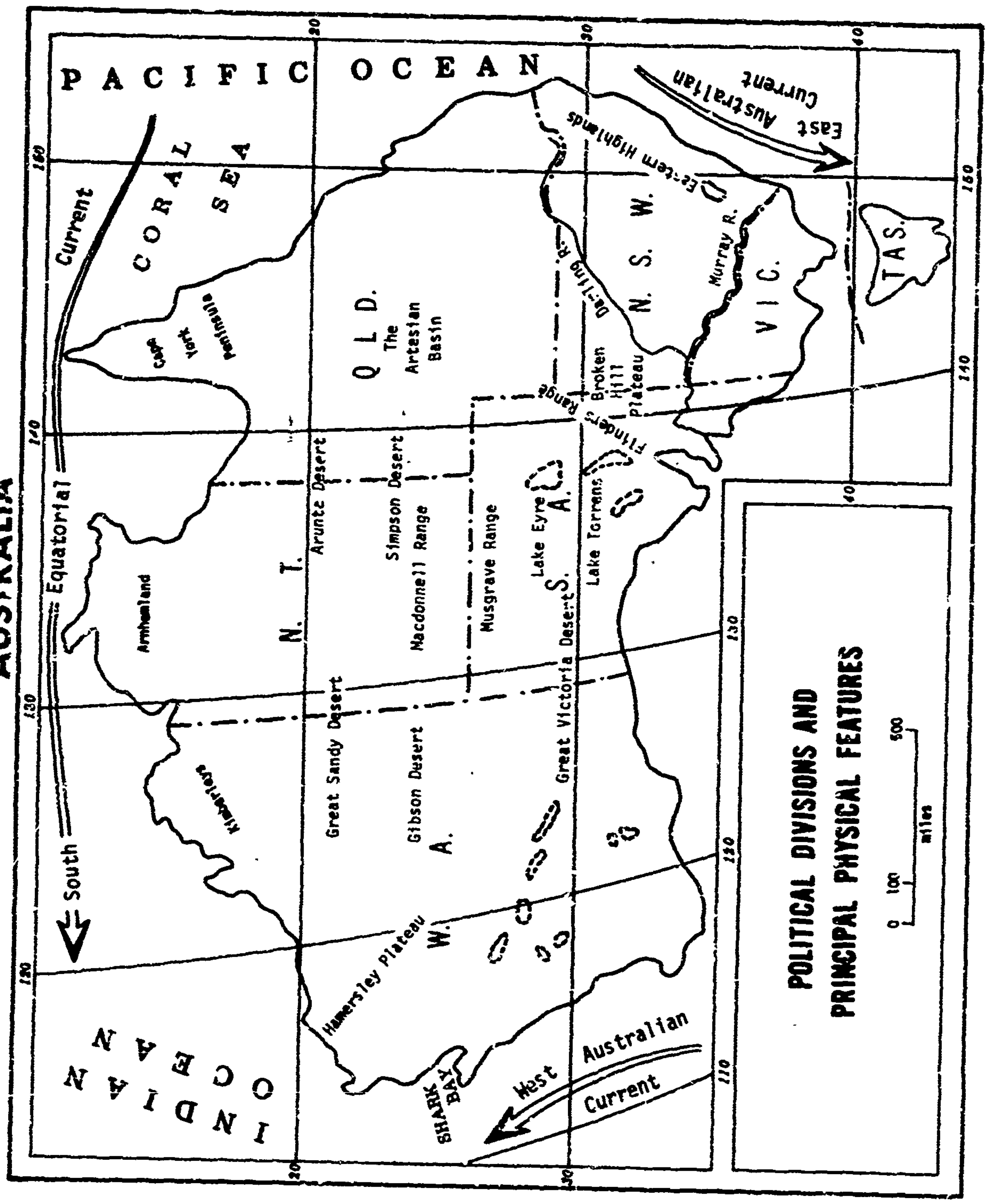

AUSTRALIA
PACIFIC OCEAN
CORAL SEA
South Equatorial Current
Cape York Peninsula
QLD.
The Artesian Basin
Darling R.
N. S. W.
Murray R.
VIC.
TAS.
Eastern Highlands
East Australian Current
Broken Hill Plateau
Flinders Range
Lake Torrens
Lake Eyre
S. A.
N. T.
Arnhemland
Arunta Desert
Simpson Desert
Macdonnell Range
Musgrave Range
Great Victoria Desert
Great Sandy Desert
Gibson Desert
W. A.
Kimberleys
Hamersley Plateau
SHARK BAY
West Australian Current
INDIAN OCEAN
POLITICAL DIVISIONS AND PRINCIPAL PHYSICAL FEATURES
0 100 500
miles

Figure 12

AUSTRALIA
DISTRIBUTION OF DRY CLIMATIC TYPES

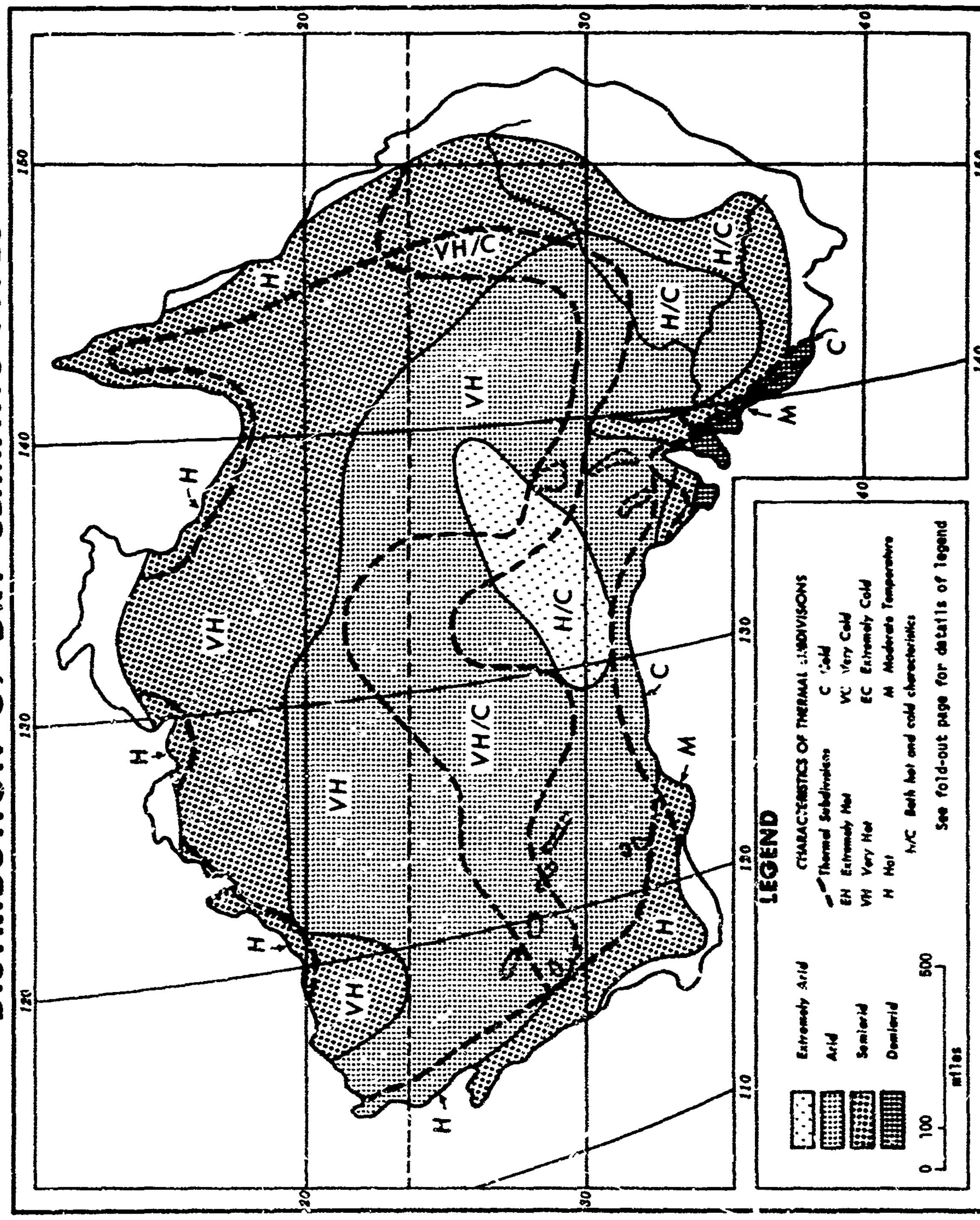


Figure 13

6. South and Central America

The Andes Mountains and the shape of the continent, tapering toward higher southern latitudes, give South America unique distribution of arid and semiarid climates. South America is the only continent on which arid climates extend to the equator on the west coast and is the only continent on which arid climates extend to the east coast in middle latitudes. The continuous strip of dry climates is no more than fifty miles wide in Peru where only the coastal plain and lower piedmont are arid. At its widest, the strip of dry climates is only a little over 600 miles across, but on the part of South America where it has that width it represents from 50% to 90% of the continent's width.

A sizable area with Semiarid climate in eastern Brazil and a strip of Semiarid and Demiarid climates on the Caribbean coasts of Venezuela and Colombia have always been somewhat surprising intrusions into the extensive area of wet tropical climates which cover nearly two-thirds of South America. Semiarid zones in western Central America are recognized as being in the rainshadow of the mountains.

a. Arid environments

(1.) Climate

Precipitation—Some of the world's driest climate occurs right along the ocean in South America in a narrow strip along the Pacific stretching 2000 miles from northern Peru to central Chile. In a 600-mile long portion between Arica and Caldera in Chile, the total rainfall during a twenty-year period amounted to one inch or less, and there is an average of only one rainy day per ten to twenty years. Near Calama, about eighty miles from the coast, it is reported that no rain has fallen in the memory of even the oldest inhabitant.

To the north, the arid region terminates abruptly near the Gulf of Guayquil where precipitation falls during the summer as a result of intertropical convergence zone activity. To the south, cyclonic storms bring rainy days each winter.

In the southern part of Argentina, the Andes prevent cyclonic storm rains from reaching Patagonia more than two to four days in each winter month. Showery days in summer are even less frequent, leaving Patagonia Arid from the mountains to the Atlantic coast.

Temperature—Maritime influence keeps temperatures Moderate along the Pacific coast except within a few degrees of the equator. High elevation dry climates generally have Cold winters, even to the equator where the mean daily minimum temperature is in the low 40's at least two months of the year. In southern Chile and southern Argentina, as many as twelve months have mean daily minima between 25°F and 4. °F.

Humidity, fog, clouds—The average relative humidities along the coast of Peru are high all months of the year. Typically, at Lima-Callao, the humidity is near 90% during the winter and slightly more than 80% during the summer. High average relative humidities throughout the year also are characteristic in the Atacama Desert in Chile. At both Iquique and Cervo Moreno, the average humidity is near 75% for the entire year.

Fog is most frequent in June to November and is particularly dense about 8°S latitude. Off the coast of Peru it can occur in any season, especially in the early morning. The northern part of Chile has little fog (one day per year at Arica and Antofagasta) but considerable low cloudiness. The cloud layer frequently meets the mountains about 2000 feet above the sea. However, during the summer the average cloudiness is low (only about three-tenths in February).

In Peru, where low stratus clouds have a base at about 1000 feet over the oceans and 400 feet over the land, a fine drizzle often falls, particularly in the winter. An area of reduced cloudiness extends into much : northwest portions of Argentina.

In the Arid regions of Argentina, th· -age monthly relative humidity exhibits greater variability. In the Arid mountains . the northwest, the relative humidity is lowest during June to September. In the southeast, the average relative humidity shows a distinct maximum in the early winter and a minimum during the summer (at Santa Cruz, 73% in June and only 47% in January).

Wind—Strong winds may be a problem in southern Chile and southern Argentina, which are subject to occasional violent squalls generated by severe winter cyclonic disturbances.

(2.) Terrain

Landforms—Along the western coast, except in the north portion of Peru, a coastal mountain range rises steeply from the ocean to heights of about 5000 feet. This range, although not completely continuous, forms an interior longitudinal valley that is the driest part of the Atacama Desert.

The Patagonian Plateau in Argentina is a series of plateaus, varying in height from a few hundred feet near streams to over 5000 feet near the base of the Andes. To the north, Patagonia gradually merges into the plains of the Pampa. Deeply entrenched valleys are found in some areas.

Along the coast of Peru, sand dunes are common and may occupy relatively large expanses of land. In Chile, where a crust deposit of salt that forms at the surface is responsible for the absence of dunes, mobility is less restricted than in other Extremely Arid regions.

The desert floor is almost colorless under the glare of the sun at noon. However, as the sun becomes lower in the sky, the stones and grit display the colors of their minerals—red, brown, blue, and yellow. Later, with lengthening shadows, the entire surface takes on a grey tone.

In the northern coastal region of Peru, where precipitation is heavier, red desert soils are better developed than they are to the south. In the central plains of Chile, on the other hand, predominant soils are weakly developed, coarse textured and full of stony deposits. In Chile, there are large stretches of grey and red soils, filled with rich minerals.

Hydrology—About fifty rivers, half of which are perennial, flow from the Andes to the Pacific Ocean. Oasis towns are generally located on these rivers. The oasis of Pica on the Piedmont Slope has eight miles of water galleries and tunnels irrigating extensive fruit orchards. Lima is a city-oasis located on the Remac River only eight miles from

the Pacific Ocean. Arequipa, located 100 miles inland in southern Peru, is an important oasis in the valley of the Chile River, about 7600 feet above sea level.

In Argentina, drainage is eastward across the Arid region, from the Andes to the Atlantic. Rivers in Patagonia include the Colorado, Negro, and Chubut.

Natural vegetation—The dry core of the Atacama-Peruvian Desert, almost completely lacking vegetation, extends from 6°S to 31°S. In Argentina, to the west and south of the moist Pampas, the grass prairie is replaced by mixed vegetation of short grass and drought-resistant shrubs. The shrubs, called "monte", become more prevalent closer to the Andes foothills. Cactus shrub is dominant over much of northwestern Argentina. In Chile, sclerophyllous (leaves heavily cutinised) scrub are found in much of the coastal fringe and central valley from 37°S to 31°S. Cactus scrub is also found on the eastern fringe of the Atacama-Peruvian Desert from 4°S to 21°S latitude.

Cultural features—Nitrate deposits and copper and silver mines of northern arid Chile are located forty miles or more inland beyond the coastal range for a length of 600 miles. Each mining area is connected to a coastal port by railroad and excellent highways go from the ports of Iquique, Tocopilla, Antofagasta, Taltal, and Chanaral almost to the Andes. Most major cities are on or within fifty miles of the coast.

b. Semiarid environments

(1.) Climate

Precipitation—The summer half of the year (October—March) is the wet season in the Semiarid and Demiarid climates from Ecuador to Argentina. Number of rainy days in the wettest months decreases southward in the Semiarid region, from more than twenty days per month near the equator to just six or seven on the Argentine Pampas. Number of rainy days in the wet season is just as variable in the Semiarid region of eastern Brazil despite far less latitudinal extent.

Semiarid and Demiarid northern South America have two dry and two wet periods, the latter coming April through June and October through December. In the Semiarid portion, wettest months have eight to twelve rainy days, in the Demiarid, only six to eight rainy days.

Marked contrast between winter drought and summer excess characterizes the Semiarid regions of Central America. Several winter months have no more than one rainy day each. June, July, and August each have from fifteen to more than twenty rainy days.

Temperature—Except where elevation keeps temperatures Moderate or permits a few Cold months, semiarid climates of South and Central America are predominantly hot. In Bolivia and Argentina, mean daily maximum temperature is in the 85—94°F range three to five months of the year. In eastern Brazil, Venezuela, Colombia, and Central America, eight to twelve months are Hot. In the Very Hot subdivision of eastern Brazil, up to twelve months of the year have mean daily maximum temperatures in the 95—104°F range.

Humidity, fog, clouds—Seasonal differences in relative humidity are as strong as the seasonal differences in temperature and precipitation. Lowest daytime relative humidities will be experienced in Central America's Semiarid regions in spring and fall and in eastern Brazil's Semiarid Very Hot region during the driest months. Cloudiness is somewhat greater in the summer six months within 30° of the equator and in the winter six months in the higher southern latitudes.

Wind—The semiarid climates on the north coast of South America and in Central America occasionally feel the strong and potentially damaging winds produced by hurricanes.

(2.) Terrain

Landforms—Most of the semiarid part of South and Central America is mountainous or highland. The mountains vary from the rounded 4000 to 6000 feet high summits in El Salvador to the Andes peaks exceeding 20,000 feet. Eastern Brazil is a rolling highland with highest levels a few thousand feet above sea level.

Hydrology—Rivers and streams are numerous, the amount of water flow reflecting the seasonal pattern of rainfall and the storage in the Andes. Thus, the streams flowing into the Parana drainage should be fullest in spring, everywhere else in late summer.

Natural vegetation—Grasses and deciduous trees are intermixed, with trees not often touching each other as in forest stands and frequently quite widely spaced. At higher elevations in southern Chile, evergreen forests are supported where precipitation is more effective because of lower temperatures.

Cultural features—The Semiarid region of Chile is the most densely populated part of that country. Transportation and communications focus on Santiago, the capital, which itself is in the Semiarid region. In Argentina, population density is not high, in comparison with the wetter Parana basin plains and coast, but the Semiarid and Demiarid west is important for the food it supplies, and it has several major cities and good connection with the Buenos Aires focus. Semiarid Venezuela, Colombia, and Central America are densely populated and include important political, commercial, and industrial centers. Semiarid eastern Brazil remains a rural region.

SOUTH AMERICA

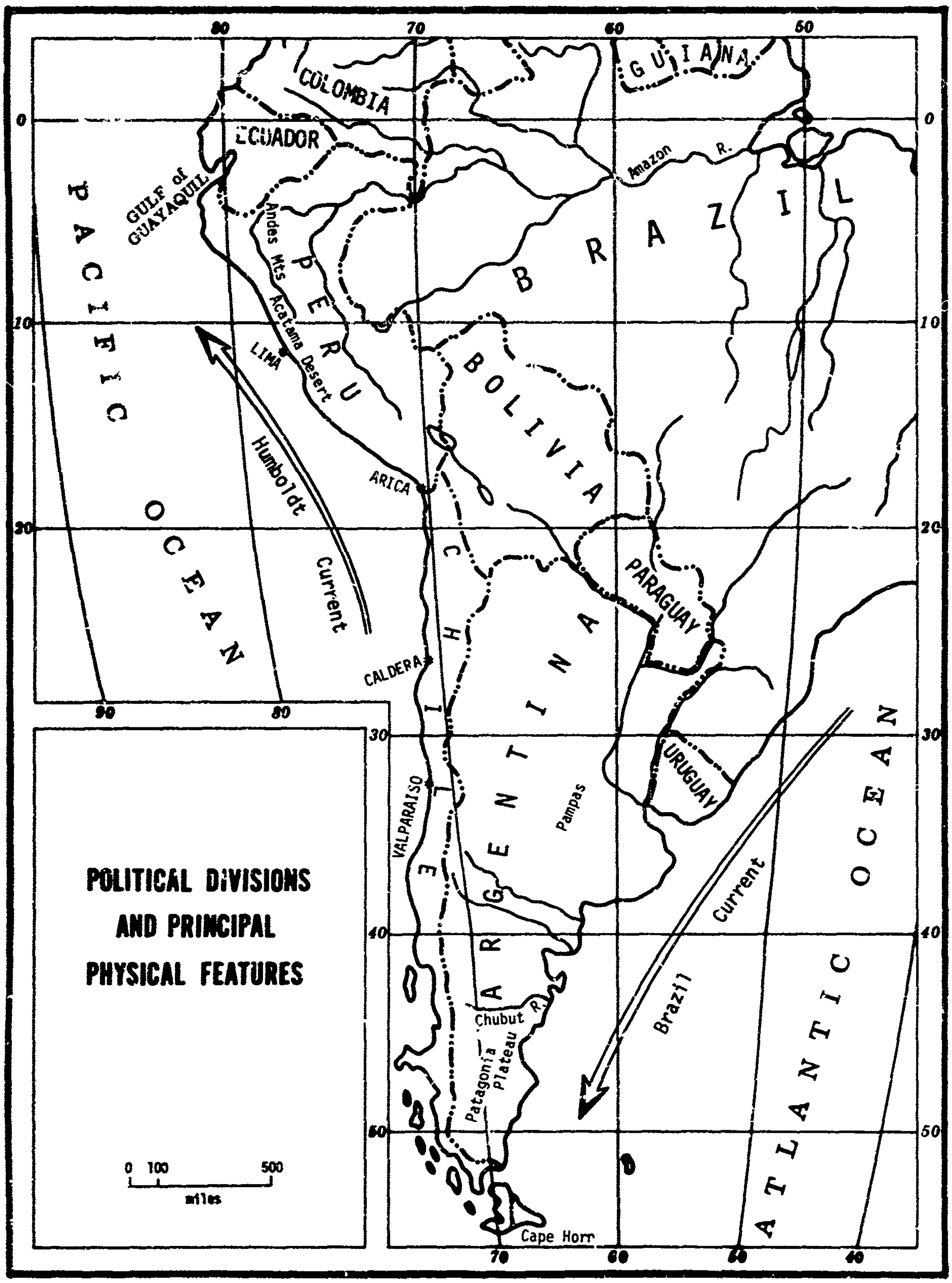


Figure 14

SOUTH AMERICA
DISTRIBUTION OF DRY CLIMATIC TYPES

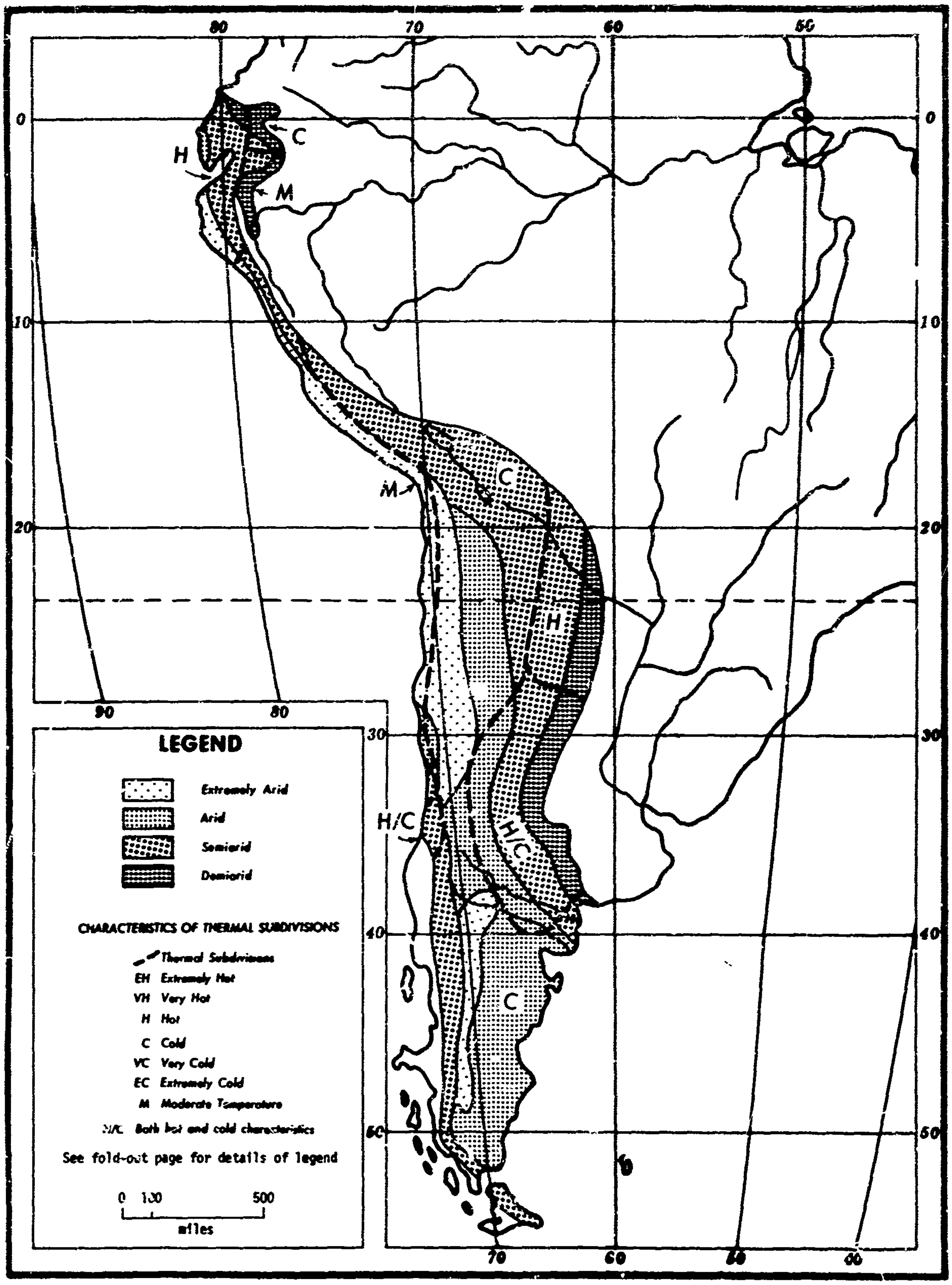


Figure 15

7. Europe

The climate in countries surrounding the Mediterranean Sea is marked by its arid summer, sufficiently dry and long to produce semiaridity for the year as a whole in about one-third of those countries' land area. The Demiarid climate in the interior of eastern Europe represents the beginning of the intensifying dryness that extends on eastward across the entire Asian continent.

Eastern Spain has the only Arid climate in all of Europe. The area is relatively small and has not been given separate environmental description.

a. Arid and Semiarid environments

(1.) Climate

Precipitation—Winter is the wet season on the Iberian Peninsula, in Italy and Greece, and on the Mediterranean islands. Cyclonic storms bring at least 0.1 inch of rain on an average of four to eight days per month from October through March. At high elevations, precipitation may fall as snow in the coldest months, but snow does not usually remain on the ground long. July and August are very dry, with an average of no more than one rainy day per month.

In the interior of eastern Europe, all months of the year have an average of at least two or three rainy days and the summer months usually have five to seven rainy days. Winter precipitation is often light snow which may remain on the ground many days, particularly in the Very Cold subdivision.

Temperature—In the Mediterranean countries, Hot summers and Cold winters predominate. A small area of southwestern Spain has two months with mean daily maximum temperature above 95°F, qualifying as Very Hot, but temperatures above 90°F at least a few days during the summer are common everywhere. Temperatures as high as 90°F are rare in the interior Semiarid and Demiarid regions, however. On the other hand, minimum temperatures below freezing are common there in as many as six or seven months, in the Very Cold region, and mean daily minima will be between 0°F and 24°F in as many as four months.

Humidity, fog, clouds—Relative humidity and cloudiness are both minimum in summer. In Spain and Greece, summer daytime relative humidities as low as 5% have been recorded. Cloudiness is maximum in winter, with periods of stratus persisting for a day or two in the Mediterranean region in association with passing cyclonic storms and for several days at a time in the interior during stagnation of weather systems.

Wind—The Mediterranean region is subject to windy periods in winter when cold winds funnel down major valleys from the mountains of south-central Europe following the eastward passage of particularly intense cyclones. The Mistral, the Bora, and the Varderac may all occasionally reach speeds of as much as 100 mph.

(2.) Terrain

Landforms—Arid and semiarid climates in the Mediterranean countries coincide with low mountains, plateaus, and narrow coastal plains. The semiarid climates of the interior of eastern Europe are associated with low mountains north to about 50°N, and with an extensive plain farther north.

Hydrology—Rivers which originate in wetter climate cross the arid and semiarid regions of Europe. Smaller streams, within the dry climate regions, are often without water during summer and fall.

Natural vegetation—Incomplete grass cover and scattered low trees are the Mediterranean arid and semiarid region vegetation. Trees usually have small, leathery leaves. Some are evergreens, others lose their leaves during the dry summer months. In the Semiarid and Demiarid interior of eastern Europe, open forests of both deciduous and evergreen species predominate.

Cultural features—Although variable in density and quality, transportation and communication are better than average. There are several major cities, notably Madrid, Athens, Prague, and Warsaw.

EUROPE

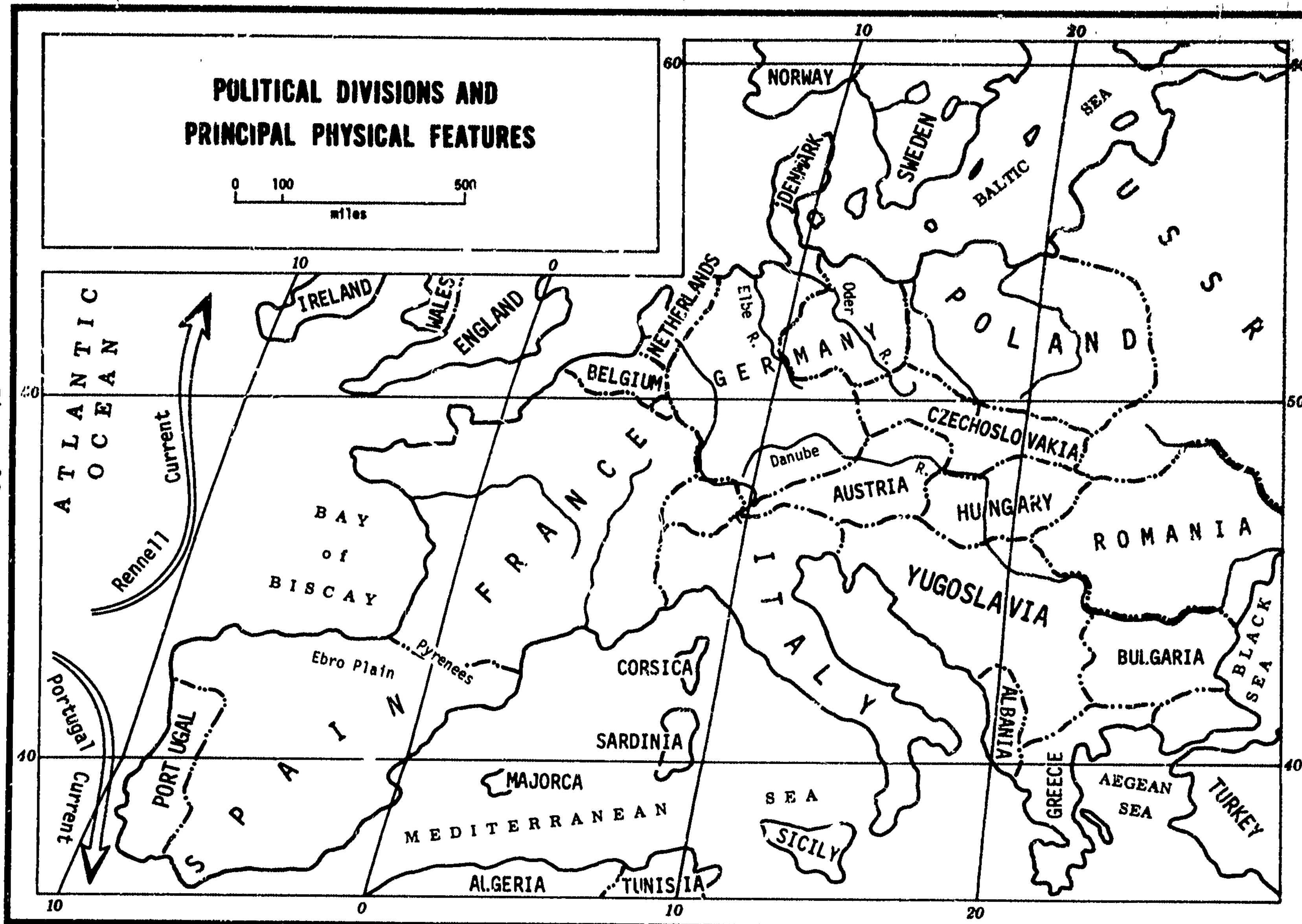


Figure 16

EUROPE
DISTRIBUTION OF DRY CLIMATIC TYPES

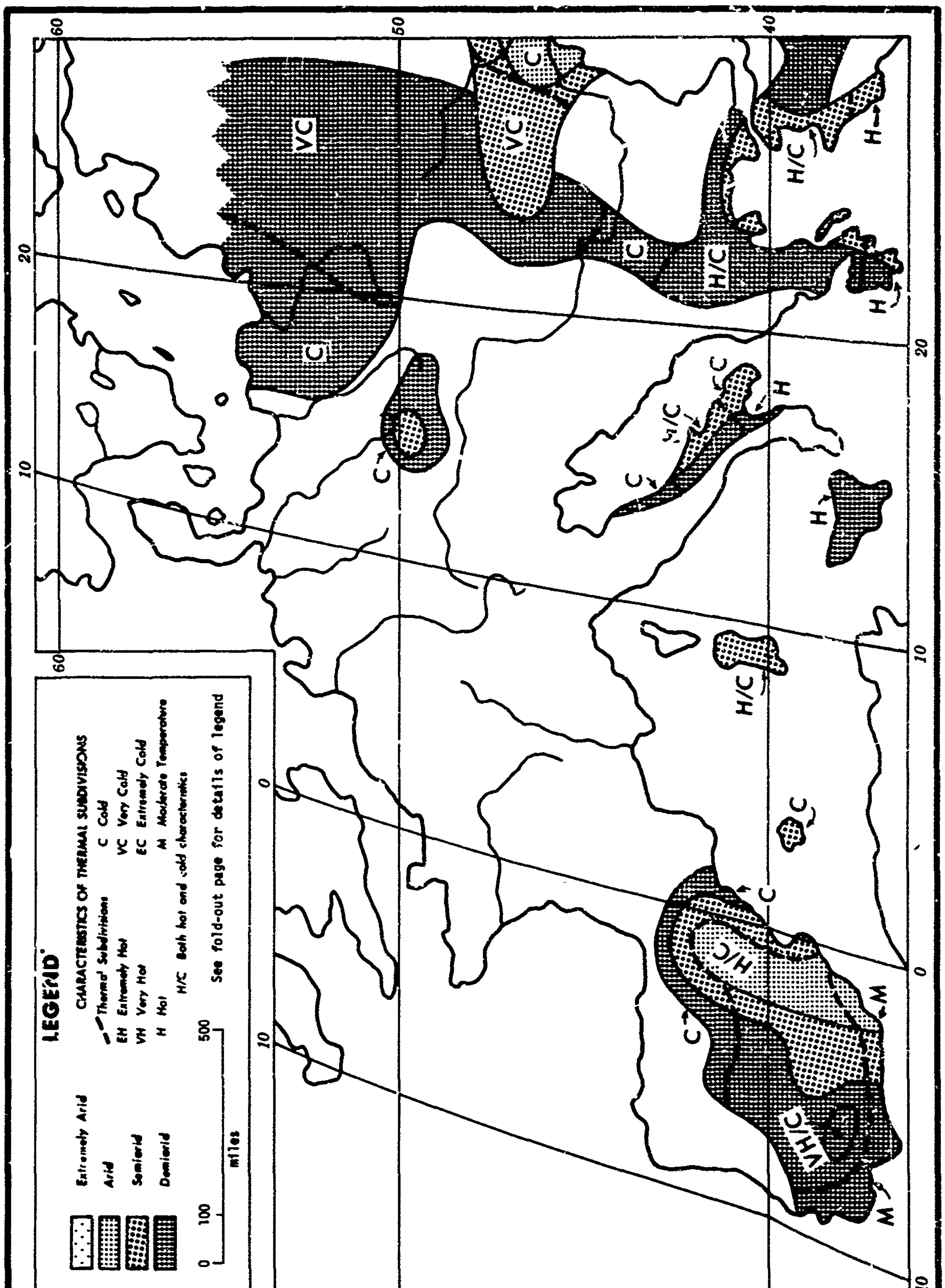


Figure 17

8. North America

Approximately 80% of North America west of 90°W is arid or semiarid, from 15°N in Mexico to and beyond 55°N in Canada. Arid and Extremely Arid climates constitute about half of the dry region in the United States. Mexico has an Arid and Extremely Arid fringe in the north and west. Canada's dry climates are mostly Semiarid with small Arid and Demiarid intrusions.

Only in Asia and North America does the full range of thermal subtypes of arid and semiarid climates occur on a single continent and within a distance of less than 1500 miles. Extremes in North America do not quite match those in Asia, but in the Extremely Hot lower Colorado valley the temperature reaches 120°F at least once in most years, while on the Extremely Cold Canadian plains the temperature falls to -30°F at least once each winter. Large range of temperature from summer to winter is the rule rather than the exception in North America, with about three-quarters of the dry climates experiencing some degree of summer heat and some degree of winter cold. The most extensive thermal subdivision is Hot summer/Very Cold winter.

The complicated pattern of dry climates and thermal subdivisions is primarily a function of the mountain and upland landscape that predominates in western North America.

a. Arid environments

(1.) Climate

Precipitation—Except where they reach the coast in subtropical latitudes, the Arid and Extremely Arid climates are in the lee of the Sierra Nevada-Cascade Range. In the Extremely Arid region, the most prolonged period without rainy days comes in spring. In the Arid area, the driest period is winter except in western Mexico. Winter months have an average of one or two rainy days. The wettest summer months have four to six rainy days. Winter precipitation is frequently snow north of about 33°N. Summer precipitation is often in the form of thunderstorms.

Temperature—Hottest temperatures in North America are observed in the Extremely Arid part of the southwestern United States. The mean daily maximum temperature averages 105°F or higher in two to four months of the year. Some extreme absolute temperatures are: Yuma, Arizona, 123°; Death Valley, California, 134°; San Luis, Mexico, 130°; Needles, California, 125°. Nights are often cool due to the dry air, at least at higher elevations. Only in the Rocky Mountains is there an extensive Arid area where summer is not at least Hot. Most of the Arid and Extremely Arid region north of 33°N has Very Cold winters, with as many as five or six months with mean daily minimum temperature 0—24°F. Temperatures as low as -60°F have been recorded in the Arid Northern Rocky Mountains.

Humidity, fog, clouds—Midday relative humidity in the Extremely Arid region averages 15—30%. In the Arid region, midday relative humidity averages 20—30% in summer and 60—70% in winter. Cloudiness is greater during winter than summer. For example, Salt Lake City has a maximum average of seven tenths in December and a minimum average of three tenths in August. Yuma, Arizona has a maximum average of two tenths in December and a minimum average of less than one tenth in June. The Southwestern United States is the sunniest portion of the country with the mean annual sunshine reaching 85% of potential over large areas.

Wind—Strong winds may occasionally accompany intense cyclonic storms, a more pronounced effect near the coast than in the interior. The entire Arid and Extremely Arid region is subject to local winds that blow out of large winter anticyclones with steep pressure gradients. These are strangest when channeled by narrow, deep valleys or mountain passes.

(2.) Terrain

Landforms—The coastal ranges of western North America rise abruptly from the Pacific Ocean. Inland, the uplands continue as a series of several parallel ranges and basins for distances of about 500 miles in Canada and as much as 1000 miles in the United States. To the east, the ranges fall abruptly to the Great Plains which, at their maximum heights, are 6,000 feet above sea level in places. The Great Plains slope to the east, grading into the Mississippi Valley. Some mountains in the dry regions of North America exceed 12,000 feet elevation in Canada, 14,000 feet in the United States, and 18,000 feet in Mexico.

The main surface features of the deserts of California, Nevada and Arizona are mountains (38%), alluvial fans and bajadas (31%), desert flats (21%), and all other features such as dunes, or bedrock fields (10%). The very small percentage of surface covered by sand dunes is a unique characteristic of arid regions of North America.

Red desert soils occur in the hottest parts of the arid southwest. Specifically they occur in northern parts of Chihuahua, Sonora, and Baja California in Mexico and in southern parts of California, Nevada, Utah, Arizona, and New Mexico. West of Alamogordo, New Mexico, between the Rio Grande and Pecos rivers are areas of sand dunes some of which are dazzling white. The Sonoran Desert consists largely of broad sandy and frequently rocky plains. The Yuma desert includes low sandy plains, extensive dunes and low, barren, boulder-strewn mountain ranges. The Mohave Desert has a relatively smooth surface in the west, but sharp-angular mountains are located in the eastern and central portions. The brilliant colors of the Painted Desert (reds, oranges, and yellows) are due to erosion of marls and sandstones. Rocky hilly areas are common in the Great Basin area. In Alberta, Montana, Wyoming, Colorado, New Mexico and Arizona, brown soils predominate.

Hydrology—Some of the major rivers (with length in miles) flowing through Arid regions of North America are: Rio Grande (1880), Colorado (1,450), Columbia (1,214), Saskatchewan (1,205), Snake (1,038), and Fraser (850). The Great Salt Lake in Utah, with 1,700 square miles of area, is easily the largest inland body of water in the dry regions.

The availability of water both from higher elevation runoff and from beneath the ground, has made irrigation possible in many regions such as the Imperial-Coachella Valley and other parts of California, Arizona, New Mexico, and Utah, as well as in other states of the region.

Natural vegetation—The Sonoran Desert is often described as an arboreal or tree desert because of the abundance of small trees, tree-like cactus (up to fifty feet tall and weighing twelve tons) and evergreen and deciduous shrubs in many areas. The Arizona Upland Desert is the center of the domain of the Saguaro cactus. The green creosote bush and the burro bush are conspicuous in the Yuma Desert of Arizona and the

Colorado Desert of southeast California. To the north of the Colorado Desert, in the Mohave Desert, the Joshua Tree is found widely spaced in combination with creosote and burro bushes Painted Desert of northeast Arizona and southeast Utah is noted for pinons and low red toothleafed sagebrush. A small-statured (one or two feet high) spiny, wood-stemmed, white-leaved salt bush known as sheep fat characterizes many parts of the region, particularly Utah. Here, in contrast with the southern deserts, few cacti are found.

Edible vegetation in desert regions includes grass seeds, tiger lily and spike rush bulbs (Great Basin area), fruit of all kinds of cacti, stems and fruit of yucca plants, and the pods of mesquite, cooked agave and pinon nuts from low-growing pines. Big barrel cactus is a source of drinking water in an emergency.

Cultural features—Transportation links provided by highways, air travel, and railroads and communication facilities (telephone, telegraph, radio, television, etc.) have been developed to serve population concentrated in some major cities and many towns. The Arid and Extremely Arid parts of Mexico have the smallest population density in that country. Southern California stands out not only as a population center but also for its industrial development.

b. Semiarid environments

(1.) Climate

Precipitation—Most of semiarid North America is east of the Rocky Mountains and on the Mexican Plateau. In this almost continuous belt of Semiarid climate from 15°N to and beyond 55°N, with an eastward extension of Demiarid climate much of this distance, winter is the dry season and summer the wet. The dry season is drier in the south, several months having averages of only zero or one rainy day per month; in the northern United States and in Canada, the dry season months average two or three days per month with precipitation, generally snow. The wet season, May through October, is wetter in the south than in the north, with fifteen to twenty rainy days in the wettest month compared with eight to twelve in the northern United States and in Canada. Variation in number of rainy days and in rainfall from year to year is perhaps greater in semiarid North America than in any other semiarid region. As many as half of all years in Semiarid United States and a quarter of all years in Demiarid United States qualify as Arid; a few years may be quite wet.

The strip of Semiarid and Demiarid climates between the Rockies and the Pacific coast mountains, extending to the coast in California, has wet winters and dry summers. Number of rainy days from November through March averages five to eight, while two to four summer months will have one rainy day or less per month.

Temperature—Latitude, elevation, and continentality are all evident in the range and pattern of temperatures in the semiarid climates of North America. As many as twelve months have average daily maximum temperatures in the Hot range, 85—94°F, on the Mexican Plateau. A large portion of the central high plains of the United States have Hot summer and Very Cold winter, with four or five months having average daily minimum temperature between 25°F and 0°F. More than half of the Canadian Semiarid and Demiarid region is Extremely Cold in winter, with two to four months when average daily minimum temperature is below 0°F. Temperatures as low as -60°F have been observed in this region.

Humidity, fog, clouds—Relative humidity is moderately high through the year along the coast, in the western mountains, and in the northern half of the interior semiarid region. Midday relative humidities, even in the driest months, average 45—60%. The southern United States semiarid climates and those in Mexico have a few dry months when midday relative humidity averages 25—45%. There is dense fog along the California coast twenty-five to fifty days a year. Cloudiness is maximum in winter from California northward through intermontane Canada, and more evenly distributed through the year on the Semiarid and Demiarid plains and on the Mexican Plateau.

Wind—Along the Mexican coast, occasional hurricanes bring potentially damaging winds. Elsewhere in the North American semiarid regions, the most frequent cause of strong winds is cold fronts or occluded fronts. On the southern Semiarid and Demiarid plains of the United States, tornadoes reach their maximum frequency in this country.

(2.) Terrain

Landforms—North America's semiarid climates are in regions of high plains, plateaus, and intermountain highlands. Most of the land is more than 1000 feet above sea level and more than half of it is between 2000 and 5000 feet elevation.

Hydrology—Several major river systems cross the semiarid regions of the United States and Canada, originating in adjacent mountains. Mexico, mostly arid or semiarid, has no sources of large rivers and it is drained mostly by short streams that have very low water or no water in the driest part of the year.

Natural vegetation—There are three principal vegetation types in the semiarid portion of North America. The plains in the United States and Canada are grassland. The intermountain section has varying density of evergreen forest. Vegetation on the Mexican Plateau is mostly shrubform broadleaf deciduous plants.

Cultural features—In the United States and Canada there are several important cities scattered through the semiarid regions, and facilities and services are generally readily available. The transportation and communications network is sparsest in the intermountain portion of western Canada. In Mexico, population density is greatest in the southern half of the Plateau and services are commensurately more available, but not of quality comparable with that in the rest of North America except in the larger cities.

NORTH AMERICA

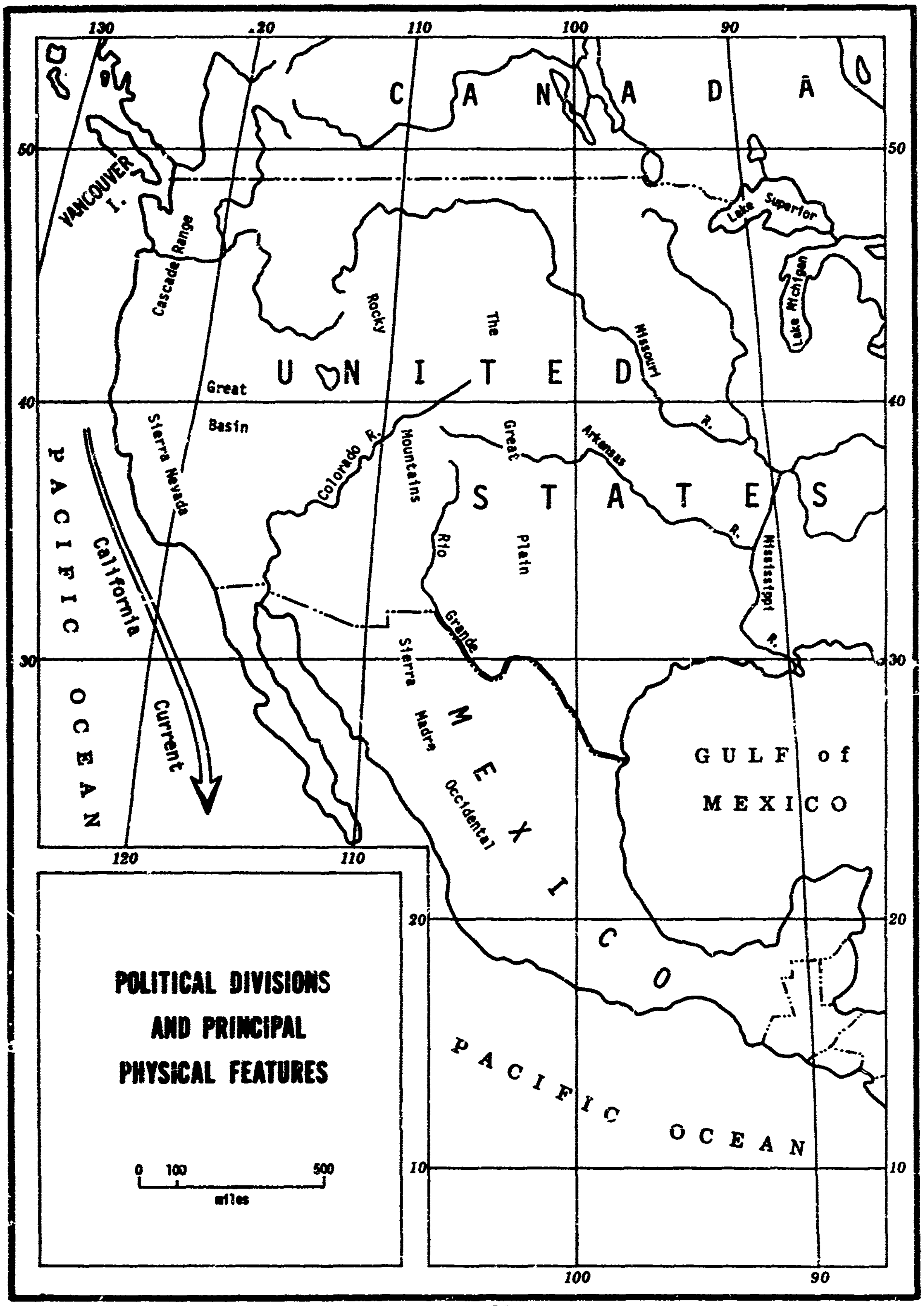


Figure 18

NORTH AMERICA
DISTRIBUTION OF DRY CLIMATIC TYPES

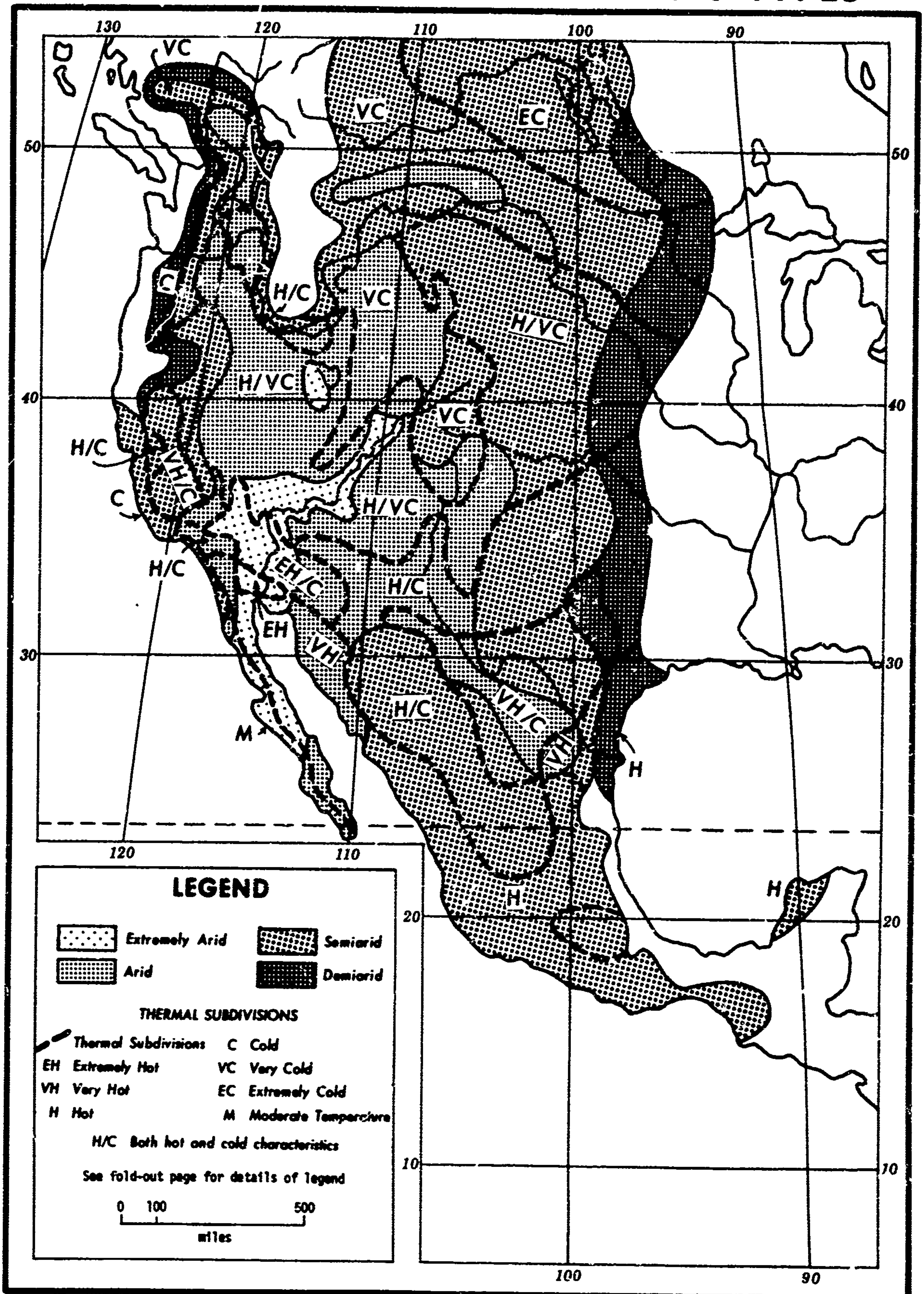


Figure 19

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APPENDIX

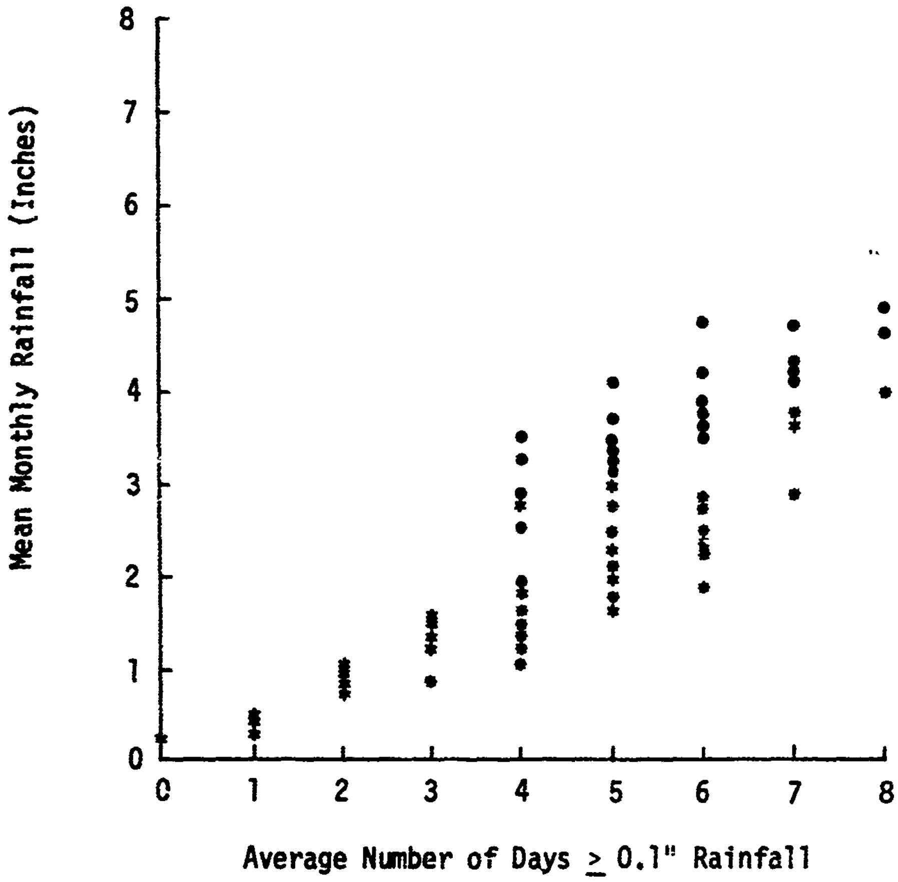
DERIVATION OF "NUMBER OF RAINY DAYS"

It was known before the decision was made to base an "index of aridity" on average number of rainy days per month that such data would not be widely available, particularly if the criterion of a "rainy day" was daily rainfall other than 0.01 in. or 1 mm. Enough experimenting had been done to permit the conclusion that an empirical relationship could be established between number of rainy days and one or more readily available climatic parameters. After daily rainfall of 0.1 in. had been agreed upon as the minimum for a rainy day, tabulations of average number of days with ≥ 0.1 in. rainfall were compiled by month for a sample of 14 United States and 5 Canadian weather stations with at least five years' record and plotted according to corresponding mean monthly precipitation amount. The resulting graph indicated that a further discriminating factor was needed.

Analysis showed that each of two or more apparently discontinuous groupings of plotted correlations evidently included data from stations with roughly similar latitudes and perhaps meteorologically similar precipitation controls (Fig. A-1). This suggested that temperature might be a useful discriminating element. Number of days per month with ≥ 0.1 in. rainfall were therefore plotted against concurrent mean monthly precipitation and mean monthly temperature for a total of 68 weather stations. These stations consisted of the original sample of 14 United States and 5 Canadian cities, an additional 13 United States stations for which the number of days with ≥ 0.1 in. rainfall could be compiled, and 36 places in Asia from Arabia to China for which tabulations of number of days with ≥ 0.1 in. rainfall were given in Tables of Temperature, Relative Humidity and Precipitation for the World [4]. Subjective best-fit categorization produced the graph (Fig. A-2) that was used to derive average number of rainy days per month for several hundred weather stations from the data sources listed in Section 3.3.

Table A-1 displays the accuracy of this technique of deriving number of rainy days from mean monthly precipitation and temperature for the developmental sample. In the full sample, 46% of the derived monthly average number of rainy days were identical with the observed number and 80% of the derived were within 1 day of the observed. For the low monthly average number of rainy days characteristic of the Arid and Semiarid climates, that is 6 and less, 59% of the derived figures were identical with the observed and 91% were within 1 day of the observed number.

Summer Months (June - Sept.)



●	Wichita, Kans.; Kansas City, Mo.; Rantoul, Ill.; Omaha, Neb.; Des Moines, Iowa; Minneapolis, Minn.; Duluth, Minn.
✲	Colorado Spgs., Colo.; Ogden, Utah; Cheyenne, Wyom.; Boise, Ida.; Rapid City, S. Dak.; Minot, N. Dak.; Great Falls, Mont.
✱	Winnipeg, Man.; Regina, Sask.; Saskatoon, Sask.; Edmonton, Alta.; The Pas, Man.

Figure A-1. Plot of days of rain versus mean monthly rainfall.

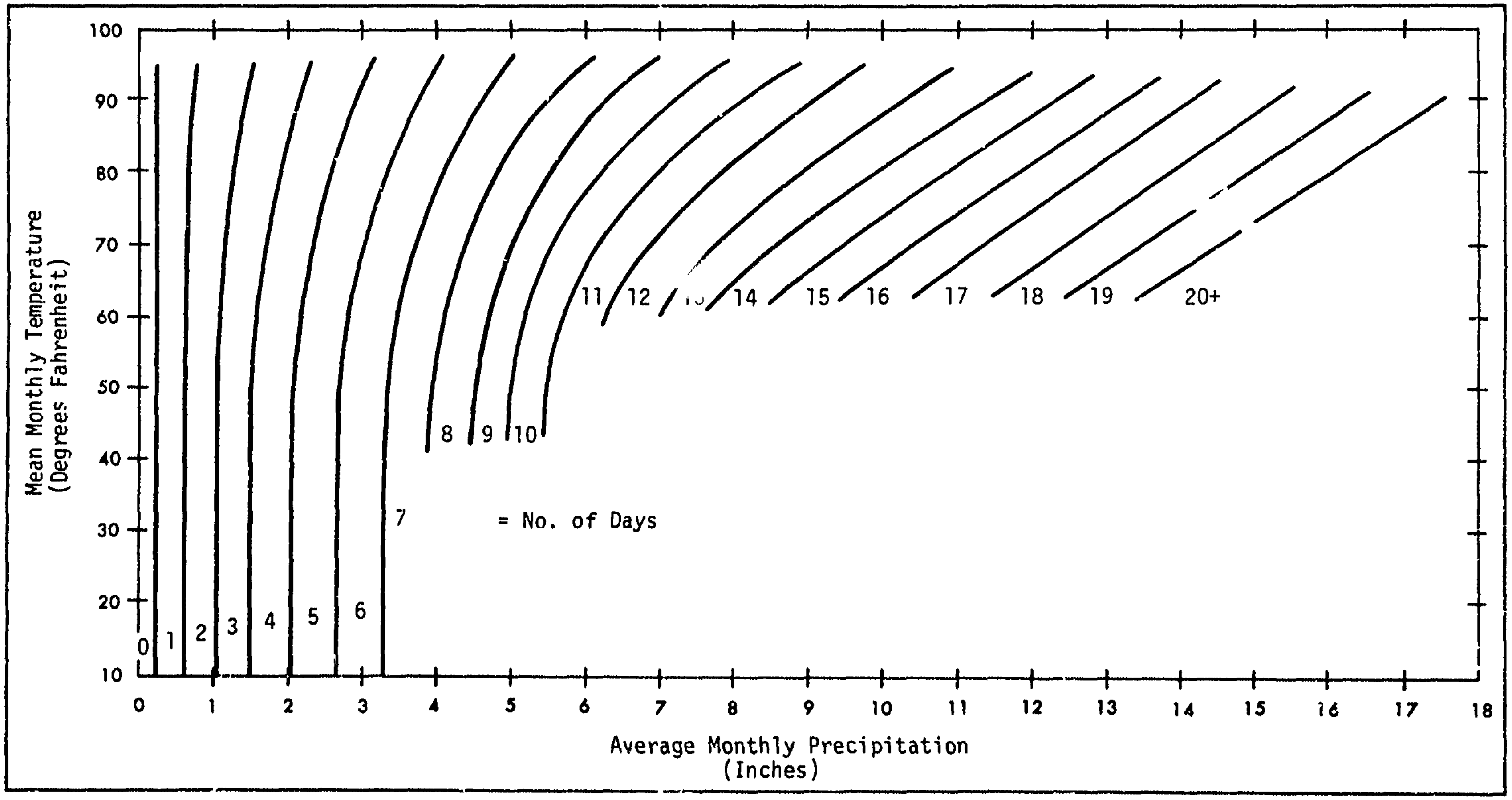


Figure A-2 Nomogram for determining number of rainy days based on average monthly precipitation and mean monthly temperature.

TABLE A-1. DISTRIBUTION OF DERIVED VERSUS OBSERVED NUMBER OF RAINY DAYS

OBSERVED Average Number of Rainy Days	DERIVED Average Number of Rainy Days: 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	65	13																			
1	3	95	26	2																	
2		4	49	17	9	1															
3		1	8	38	23	4	3	2	1												
4		1	4	16	26	22	9	2	2	1		1									
5				5	12	35	20	5	4		2										
6					4	11	25	15	7	4		1	1								
7					1	1	8	16	13	5	3	1	1	1							
8							6	6	6	3		1									
9							1		3	2	6	4	2	1		1					
10							1		1	3	4	4	1	1	1	1					1
11									1	4	1	3	5	3	4					1	
12												4	3	5	2	1					
13										1	1		1	2	2	2	1		1		
14												1	1		1	3	2	1			1
15										1				1	1	1	3	3	1	1	
16																2	2			1	1
17															1	1		1	1	1	
18													1				3	2	1		1
19																		1	1		2
20																1				1	1

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13. ABSTRACT

This report identifies and maps limits of arid and semiarid regions of the world through application of aridity criteria quantitatively expressed in terms having military significance. Because the dry world includes a wide range of thermal characteristics, from extremely hot deserts of North Africa to extremely cold semiarid Asia, subdivisions were based on features of monthly temperature.

The worldwide distribution of arid and semiarid conditions is presented on one map. Details of both aridity and thermal classification are shown on eight continental and sub-continental maps for Eurasia, Southwestern Asia, North Africa, South Africa, Australia, South and Central America, Europe, and North America. Aspects of climate and terrain that are of significance to Army operations are described.

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CLASSIFICATION OF WORLD DESERT AREAS

by

George M. Howe, Lawrence J. Read, John T. Ball,

George E. Fisher and Gordon B. Lassow

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